BIOLOGY

BOOK
PRODUCTION
WAR ECONOMY
STANDARD

THIS BOOK IS PRODUCED
IN COMPLETE CONFORMITY WITH
THE AUTHORISED ECONOMY STANDARDS

GENERAL SCIENCE FOR SCHOOLS

CHEMISTRY. By A. W. WELLINGS, M.Sc.

PHYSICS. By W. ASHHURST, B.Sc., M.Sc. (Tech.

BIOLOGY. By F. MARY GREEN, M.A., PH.D.

GENERAL SCIENCE FOR SCHOOLS

BIOLOGY

By F. MARY GREEN, M.A., Ph.D.

Head Mistress of Abbeydale Grammar School for Girls, Sheffield

LONDON

JOHN MURRAY, ALBEMARLE STREET, W.

Made and Printed in Great Britain by Butler & Tanner Ltd., Frome and London

FOREWORD TO GENERAL SCIENCE FOR SCHOOLS

The notable increase in the number of General Science Courses in Secondary Schools during the past decade shows that the subject will occupy a prominent place in any future curriculum. Education should bring about the fullest possible development of the boy and girl both as an individual and as a citizen. Any scheme of Educational Reconstruction must recognize the part which General Science can play. It can develop minds trained in differentiating between substantiated facts and mere propaganda. It can present the main aspects of the modern world-wide environment, including industry, agriculture and communications, together with the social relationships involved, and hence it can develop a sense of social responsibility as a world citizen. Finally, it has an important cultural value, for it can provide many real and lasting interests.

In the early days of General Science much was written, and said, about the detailed planning of a General Science course, particularly by the Science Masters' Association and the Association of Women Science Teachers. The chief Examining Boards gave every encouragement to the development of General Science in schools by introducing it as a subject for the School Certificate Examination. These earlier years of General Science teaching in schools provided much valuable experience. In the first place it was obvious that General Science had come to stay. In fact, the number of candidates taking General Science in some examinations exceeds that taking any other separate Science subject and, as a result, several Boards have introduced syllabuses for two credits in the subject. At the same time, the early schemes were by no means perfect, and, recently, a great deal of revision and overhauling has been done by the Professional Associations and the Examining Boards. The books of this General Science series are written in the light of these modern develop-

ments; they are suitable as textbooks for the revised syllabuses.

The purpose of the first three books is threefold—first, to encourage skill in observation and experiment, and to refine the raw material of observed facts by scientific methods; secondly, within the general educational framework, to develop ability to think and reason in a logical, systematic way, and to cultivate disciplined imagination allied with impartial judgement; thirdly, to interest the pupils in the study of their material environment, and to show how profoundly scientific progress has affected man's individual and social development.

The three books—*Chemistry*, by A. W. Wellings, *Physics*, by W. Ashhurst, and *Biology*, by Dr. F. M. Green, have been planned with these aims in view continually; and the authors have collaborated in all the various stages of their preparation. The contents of the books are based on the authors' teaching courses. They owe much to the pioneer work of the Science Masters' Association in its publication of the two Reports on the Teaching of General Science, and to many profitable debates on General Science at meetings of the Science Masters' Association and Association of Women Science Teachers. Moreover, the authors have been helped by discussions with other teachers on committees for the drafting of new examination syllabuses. Finally, some debt is due to many School Certificate candidates whose answers have often been as straws in the wind giving their proverbial indication. Cross-references are provided in all three books.

The authors gratefully acknowledge permission from the following Examining Boards to include selected questions from School Certificate papers: University of Cambridge Local Examinations Syndicate, Oxford Local Examinations Delegacy, the Senate of the University of London, and the Northern Universities Joint Matriculation Board. They wish to thank, also, Mr. H. E. Wilmott of John Murray whose genial encouragement and good advice did much to ease the labour of authorship.

PREFACE

The introduction of General Science as a school subject has been accompanied by substantial progress in the teaching of Biology, and the successful teaching of Biology depends largely on a sound basis of Physics and Chemistry. It is quite impossible to begin to understand the living processes without such a basis. At the same time it cannot be emphasized too strongly that Biological teaching should inculcate sound training in first-hand observation of animals and plants. To read about the tadpole or the marigold is not enough, the organisms themselves must be observed. Similarly, it is most essential to carry out the experiments (or similar ones) instead of merely reading about them.

In this book considerable attention is paid to the Biology of Man ; and Man, together with rabbit, are used at all stages to illustrate the living processes of Mammals. Attention is also paid to the applied aspects of Biology, and prominence is given to such topics as growing of crops, suitable diet, bacterial diseases, harmful insects, and so on.

The material in this book covers the requirements in Biology of the revised School Certificate General Science syllabuses for two credits of all the Examining Boards. The questions at the ends of the Chapters are not, as a rule, actual examination questions, for often these cannot be answered without knowledge of a wider field than the material of one chapter. However, many of the questions are designed to test the candidate's power of applying his scientific facts to new problems, and in this respect they indicate the present tendency of School Certificate questions. Most of the questions are longer than the average School Certificate question ; in fact, the majority of the answers will require about forty minutes. The length can easily be shortened by omitting part of the question.

In the past too much importance has been attached to the use of technical terms. These should be regarded in their proper perspective as convenient labels. Some children use

technical terms much more freely than others, and, because they are convenient, many technical terms are included in this book. However, the minimum number of technical terms have been printed in heavy type ; these are terms worth remembering, such as annual, ovary, pancreas, etc. Others, in ordinary type, such as trachea, chitin, dentine, need not be memorized, since the structures indicated by them can be described in other ways.

My grateful thanks are due to the Oxford University Press for permission to include Figs. 43, 56 and 101 and to adapt Fig. 100 ; to Messrs. Cassell for permission to include Fig. 19 and to adapt Fig. 82(*a*) ; to Nouveau Petit Larousse, Larousse éditeur, Paris, for permission to include Fig. 56 ; to Messrs. Routledge for permission to adapt Fig. 82(*b*); and to Messrs. John Murray for permission to include or adapt a few diagrams from their other publications. I should like also to express my warm thanks to my father and mother for their help throughout the writing of this book ; to Mrs. Rupert Livingstone for the care she has taken with diagrams ; and to Miss Eleanor Williams for her comments on the first draft.

F. M. G.

September, 1945.

CONTENTS

CHAP.		PAGE
I.	Plant Form	1
II.	Animal Form	19
III.	Soil	32
IV.	Water in Plant and Animal Life	41
V.	Circulation of Blood	53
VI.	Some Chemical Substances of Plant and Animal Bodies	65
VII.	Plant Nutrition	70
VIII.	Animal Nutrition	89
IX.	Respiration	105
X.	Getting Rid of Waste	119
XI.	Animal Behaviour	125
XII.	Plant Responses	147
XIII.	Reproduction in Plants	155
XIV.	Reproduction in Mammals	175
XV.	Growth	184
XVI.	Vertebrate Animals	194
XVII.	Insects	209
XVIII.	Some Lowly Plants and Animals	220
XIX.	Fungi, Bacteria and Viruses	234
XX.	Life	246
	Index	249

CHAPTER I

PLANT FORM

Biology is the science of living things, of grass, cows, flies, spiders, buttercups, worms, ferns, trees, roses, man, mosses, slimes, moulds, germs. What a motley collection this sounds ! Yet we shall see that all have certain features in common, qualifying them as living organisms rather than inanimate matter. One feature is that they are not static ; many of them move about from place to place, and all of them undergo changes in size and form, which we call development. Biology is the study of how these living things maintain themselves, and it sets out to answer the question : " In what does the process of living consist ? "

It is not possible to answer this question simultaneously for all kinds of living things. Let us start with ourselves and with some of the larger living things which surround us. Dogs, cats, cows, rabbits and human beings belong to a group of animals called Mammals. Grasses, trees and buttercups belong to the Flowering Plants, a group which includes nearly all the plants which one meets in ordinary life. Let us try to find out how a mammal lives and how a flowering plant lives.

Our first object is to understand the bodily form of mammals and flowering plants, for unless we know about the structure of the body we cannot hope to fathom its working.

THE MARIGOLD PLANT

In Fig. 1 the chief structures in the plant body are shown. It is convenient to divide the body into a root system and a shoot system. The shoot system consists of the stem with the leaves arranged spirally on it. The leaf has a much branched system of veins. The angle between the leaf and the stem is called the **axil**, and here there is a bud. Many of the buds grow out into branch shoots which repeat the

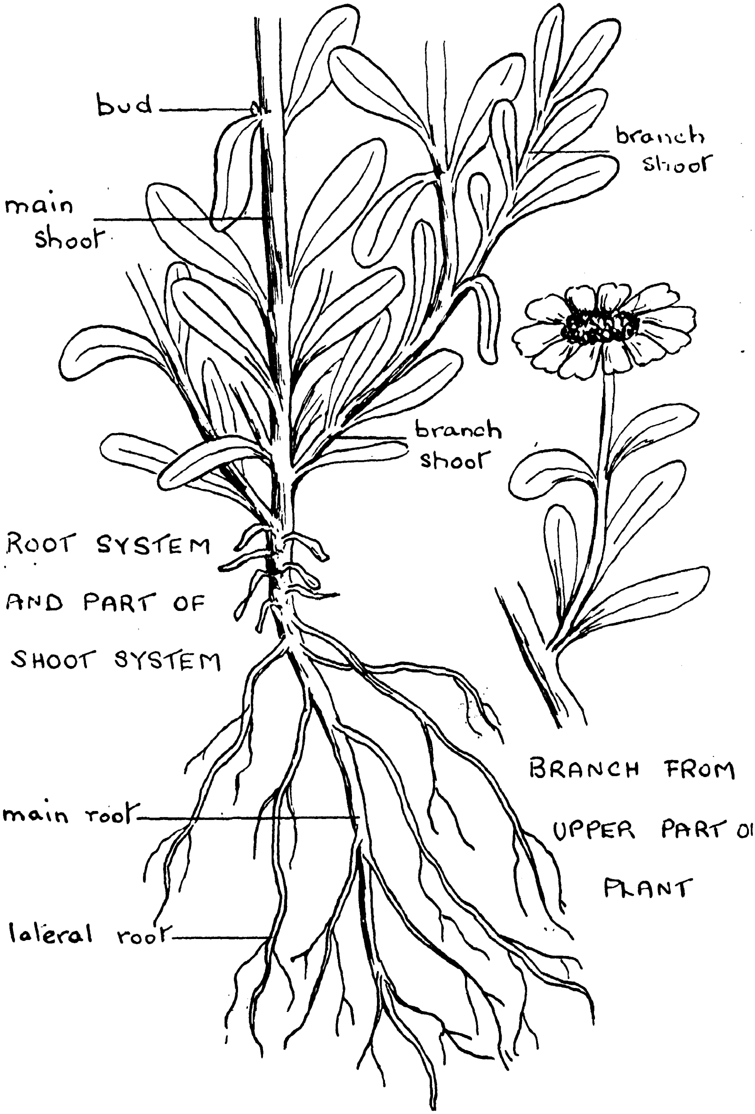


FIG. 1.—Marigold plant.

structure of the main shoot. At the top of the shoot there is usually a head of flowers. The actively growing regions are the tips of the shoots and the buds; these are called **growing points.** The root system has a main root with much branched laterals growing from it. There are no buds or leaves on any of the roots. Near the tips of the roots are some delicate hairs, the **root hairs**; these are difficult to see if the plant has been uprooted from soil because they are so easily damaged. If you grow mustard seeds on blotting-paper in a moist atmosphere it is easier to see these root hairs for they develop particularly well in a moist atmosphere. The root hairs of mustard are shown in Fig. 60.

HABITS OF PLANTS

All flowering plants are built on the same fundamental plan of root system and shoot system as the marigold; and yet, at first sight, there seems little resemblance between the marigold and the carrot, or between the marigold and the oak tree. This is because of variation in the duration of growth (or **habit**) of the plant. To begin with, we may distinguish trees and shrubs as plants with continually developing shoot systems which persist from year to year. Plants, other than trees or shrubs, are said to be **herbs.**

Annual herbs.—The marigold is said to be an **annual plant.** After it has formed its seeds it dies, and survival depends on the seeds only. Other annual plants are peas, beans, Virginia stock, poppy, groundsel, shepherd's purse. Annual wild plants have some difficulty in establishing their seeds, and they are commonest in places where there is some unoccupied soil, such as in gardens and cultivated fields, where they form troublesome weeds. The best way to get rid of weeds is to pull them up or hoe them in when young, before they flower and set seed, otherwise the next generation of weeds is bound to grow up, and often makes its appearance within a week or two of the fall of the seed. In fact, the term annual is misleading since many of the plants may produce several generations in a year. Any gardener knows that several crops

of groundsel may have to be pulled out in the course of the growing season.

Biennial herbs.—The conspicuous feature of the carrot plant is its much swollen main root which contains abundant food (see Fig. 2). Such a dominant main root is said to be a tap root ; the lateral roots are extremely thin in comparison with the tap root. The shoot system of a carrot at the end of the first growing season consists of a crown of much divided compound leaves attached to a very short stem, which remains at soil level. In this form the carrot plants are usually dug up out of the ground and the swollen tap roots are used as vegetables. This digging up curtails the natural life cycle of the carrot. If left to itself, it goes into a resting condition through the winter. In the following spring, the apex of the stem starts to grow, and during the summer it develops into a tall shoot system with leaves and flowers. During this growth the food supply in the tap root is used up, and, after flowers and seeds are produced, the whole plant dies. Thus, in its natural life cycle, a carrot develops for two growing seasons with a resting period in between. It is said to be a **biennial plant.** Many common crop plants with swollen

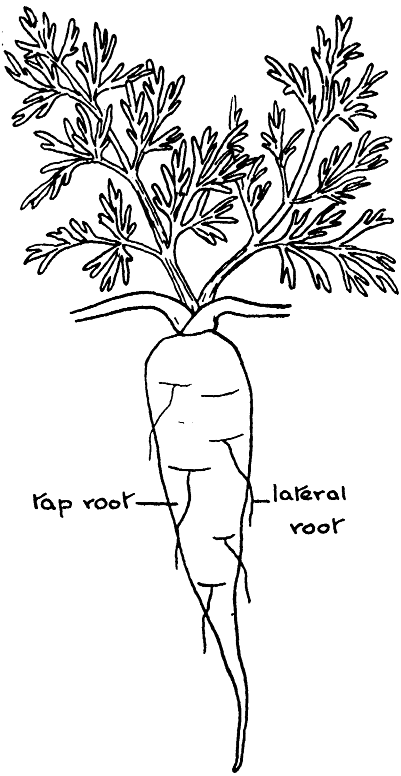


FIG. 2.—Carrot plant at the end of the first growing season (only two leaves shown fully).

roots such as swede, turnip, mangold, beetroot, are biennial plants.

Perennial herbs.—A great many plants live longer than annuals and biennials. Such **perennial plants**, as they are called, include grasses, daisies, dandelions, potatoes, delphiniums, lupins, mint, tulips, crocuses and many others, as well as trees and shrubs. Now, except for the trees and shrubs, none of these plants reaches any great stature, because much of the shoot system is renewed every year, and only the parts which are underground or at soil level persist during the winter. These plants are called **perennial herbs.** Some of them are illustrated in Figs. 3 to 8. All of them store up food in underground parts during the active season, then they pass through a resting stage and growth is renewed in the next active season at the expense of the stored food.

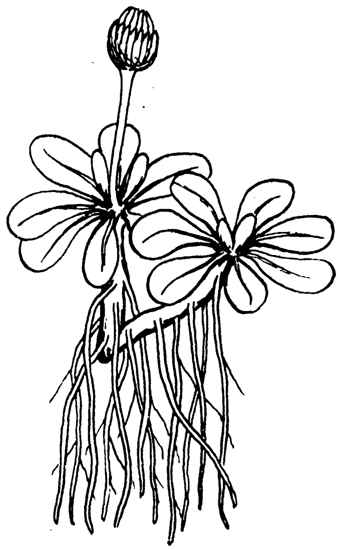


FIG. 3.—Daisy plant.

The daisy (Fig. 3) is a rosette plant producing leaves at soil level only, but delphiniums and lupins produce leaves on their aerial shoots as well as at ground level. In all these plants the swollen underground stem may branch occasionally so that in time there is a cluster of plants. Gardeners divide the clusters of lupins and delphiniums and move each of the units to a new place in the garden where there is adequate room.

Grasses have a very successful tufted method of growth which enables them to cover large areas. The original shoot branches very near its base and the lateral shoots in their turn branch very near their bases (see Fig. 4). This process is repeated several times so that the grass plant consists of

almost parallel shoots which have arisen very close together. This closely tufted method of growth enables the grass plant to establish itself firmly over the whole soil and it is very difficult for any other plant to colonize the area once the tussocks of grasses are firmly established. The growing apex of a grass

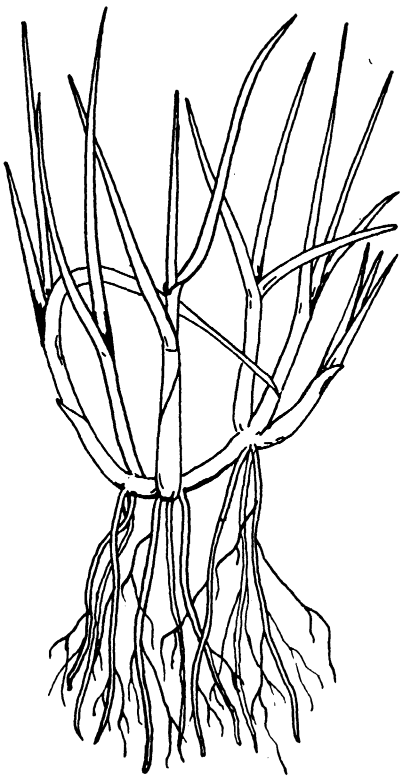


FIG. 4.—Typical grass plant.

stem remains enclosed within the leaves until flowering takes place. Before the resting season all the flowering stems wither away and only the stems and leaves at ground level are left. The grass leaf is of a special kind, since a large part of it sheathes the stem; the exposed blade is strap shaped and has parallel veins.

Mint (Fig. 5) has a straggling method of growth by means of creeping branched underground stems called **rhizomes.** Some of the buds on these grow into aerial shoots with leaves and flowers during the active season. During the resting season only the underground parts exist. The older parts of the rhizomes gradually decay and hence the new parts, together with the aerial shoots produced from them, are isolated from one another and become new units. This is a method of reproducing the plant and it is distinguished as **vegetative reproduction** in contrast to reproduction by seed. Other

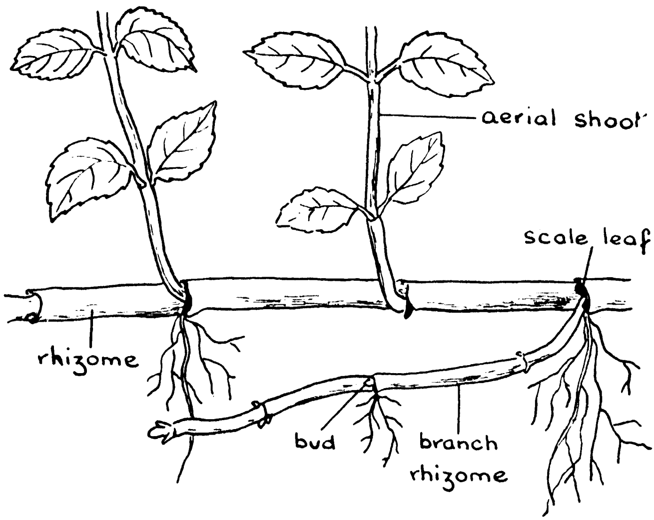


FIG. 5.—Mint.

plants with rhizomes are perennial sunflower, iris, convolvulus and couch grass. The last two are very troublesome garden weeds. It is almost impossible to remove the whole of the rhizome system, and any small pieces left can develop into new plants.

The potato plant (Fig. 6) has rhizomes and the ends of these swell up into structures called stem tubers. These have much reduced scale leaves and buds on them (the "eyes" of the potato). As a rule, the potato tubers are dug up and used by man, but, if left to itself, all the plant withers before the

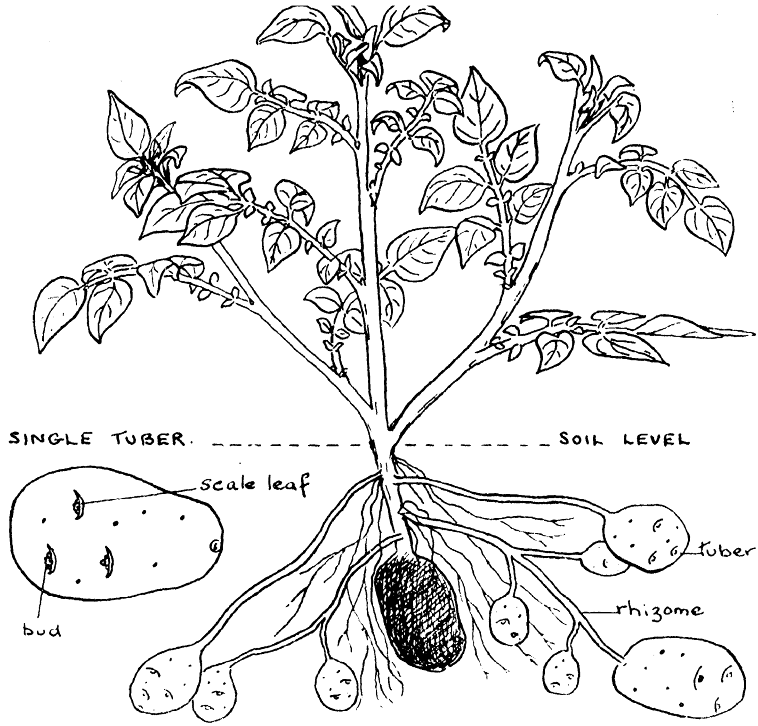


FIG. 6.—Potato plant.

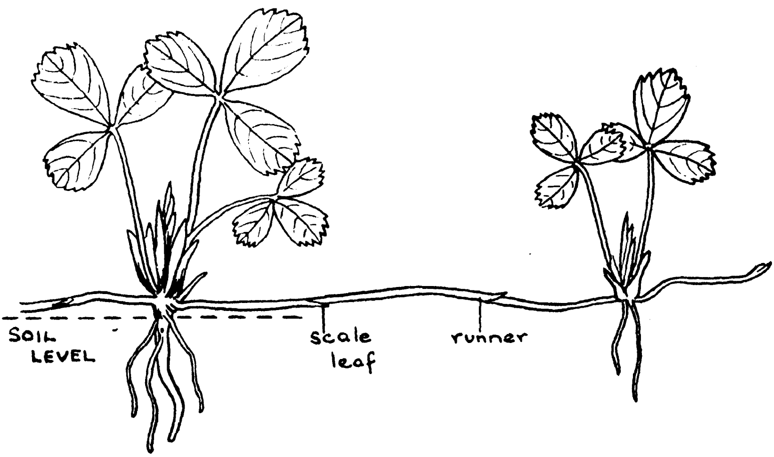


FIG. 7.—Strawberry plant showing runners and new plant.

resting season, except for the tubers. These remain in the soil and the buds develop into new plants during the next growing season. It is obvious that potato tubers are very efficient organs of vegetative reproduction.

Some plants straggle along the surface of the ground instead of underground. A strawberry plant (Fig. 7) develops long axillary branches, which grow along the surface of the ground; they bear much reduced scale leaves at intervals, and finally produce a terminal bud, from which a new plant develops. Such a horizontal shoot growing along the surface of the ground is called a **runner**. The new plant forms its own leaves and roots, and, until it is fully established, it is dependent on food material transported into it from the parent plant via the runner. When roots and leaves are adequately developed the new plant is independent, and finally, at the end of the growing season, the runner withers away. Strawberry growers take advantage of these new plants as a method of propagation. Obviously, more vigorous plants will be produced if the number of runners is limited to a few, and, as a rule, only three or four are allowed to develop. Other plants producing runners are creeping buttercup and ground ivy.

Daffodils and tulips pass their resting season, summer and autumn, in the form of large **bulbs** heavily stored with food (Fig. 8). In the growing season, late winter and spring, flowering shoots are produced at the expense of the food in the bulb, and, at the end of the growing season, new bulbs are produced within the parent bulb to survive through the next resting season. Several new bulbs may be formed in this way inside the parent bulb and thus vegetative reproduction takes place.

Crocuses survive the resting season (summer and autumn) as corms. A corm is a hard solid piece of stem bearing one or more buds on it (Fig. 8). The buds develop in the growing season at the expense of the stored food in the corm. Then towards the end of the growing season the bases of the flowering stems swell up to form the new corms. Here again vegetative reproduction has taken place.

Trees and shrubs.—The only plants capable of attaining any

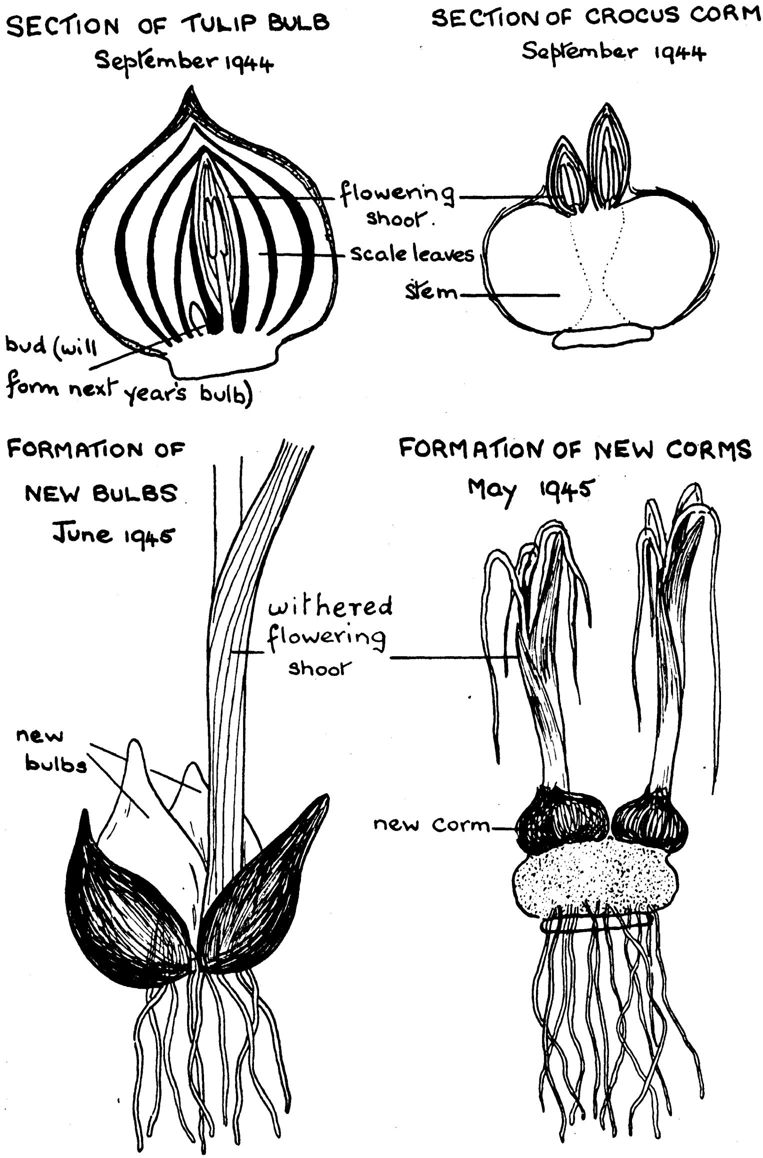

SECTION OF TULIP BULB
September 1944
SECTION OF CROCUS CORM
September 1944
flowering shoot.
scale leaves
stem
bud (will form next year's bulb)
FORMATION OF NEW BULBS
June 1945
FORMATION OF NEW CORMS
May 1945
withered flowering shoot
new bulbs
new corm

FIG. 8.

great stature are trees and shrubs. In these the aerial shoot system persists year after year without dying down to ground level during the resting season. A great many trees and shrubs lose all their leaves in autumn at the onset of the resting season; these are said to be **deciduous.** Others, such as the holly, cherry, laurel and privet, lose their leaves gradually, a few at a time, in the course of eighteen months or so, and hence there are always leaves on the tree. In winter, the resting season, the majority of the leaves formed in the previous growing season persist. In the next spring there are the newly formed leaves as well as those formed in the previous growing season. Such trees and shrubs are said to be **evergreen.**

A shrub is much branched without any obvious main trunk. Shrubs used in hedges branch very profusely indeed and when the hedge is cut more branches arise from the lower buds. Hawthorn is a most successful hedge plant used by farmers to border their fields. Trees usually have a main trunk which is dominant for a certain distance. In coniferous trees, such as spruce and pine, the trunk dominates to the very tip of the tree.

It is easy to understand the method of growth of a tree if we trace the history of one of its buds (see Fig. 9). Let us consider the bud of a lime tree in December 1943. It is covered by hard scales which protect the young shoot inside. This shoot has miniature foliage leaves, each being enclosed by two thin green scale leaves. In the following spring the shoot elongates, using food material stored in the twigs and trunk, and the hard outside scales are forced apart and gradually they fall off, leaving a series of scars showing the position of the bud. The inner thin scales persist for a time in pairs at the base of each leaf stalk. Later in the year, about July 1944, the shoot has the appearance seen in the lower drawing; the leaves have been fully expanded for some time, and are in full swing of food production (see Chapter VII). Axillary buds have already started to develop in the axils of the leaves. In the lime tree, as in many others, the apex of the shoot above the last leaf does not survive, so that by July there is a leaf and its axillary bud at the tip of the stem. The

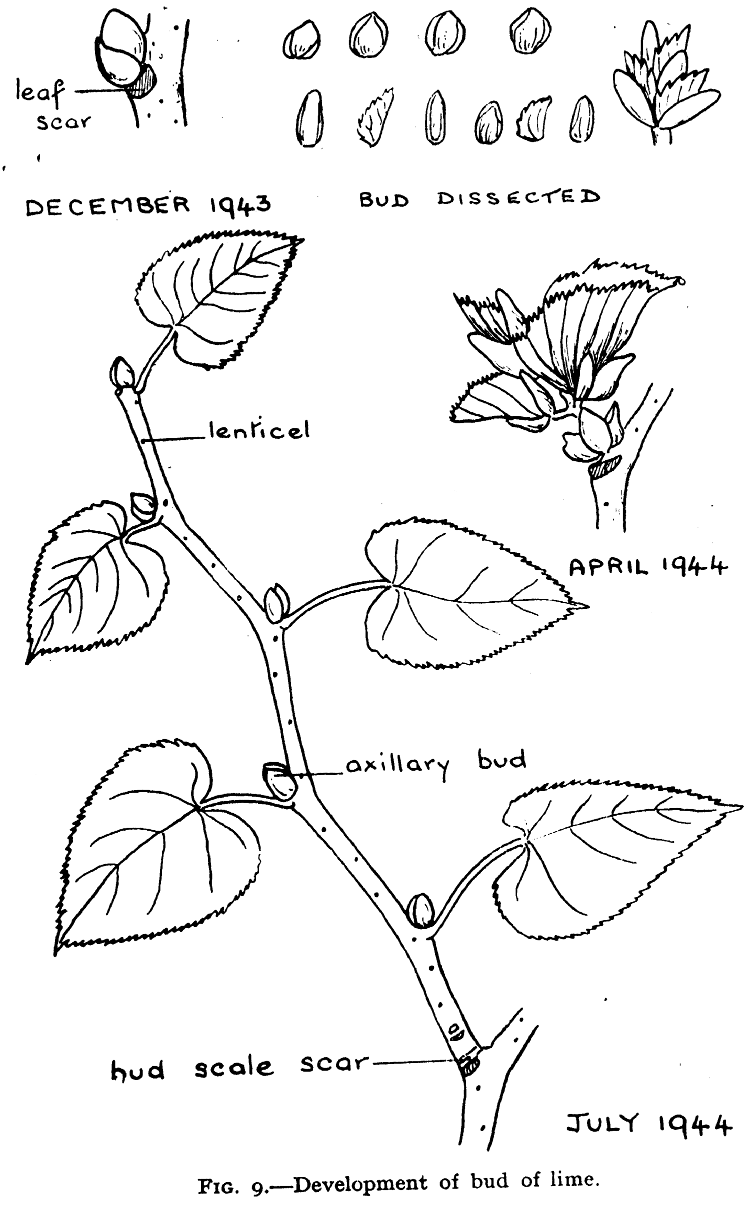
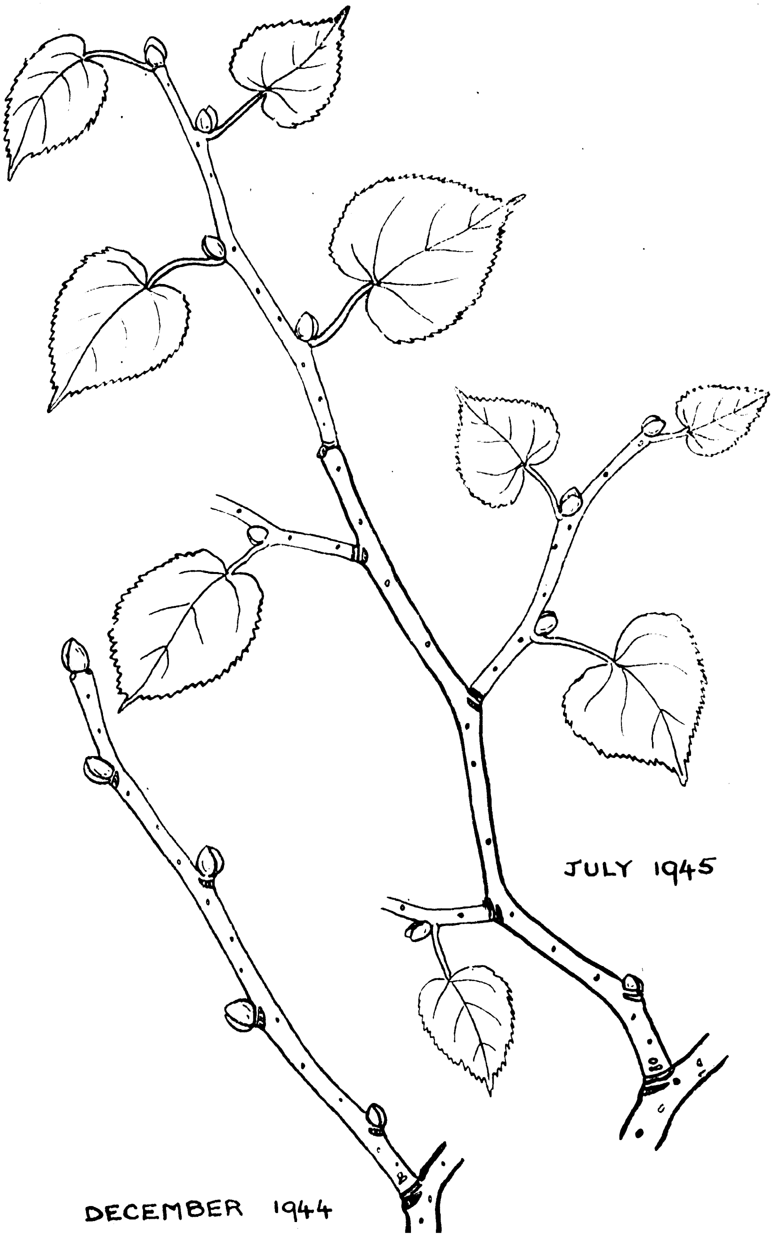


FIG. 9.—Development of bud of lime.


JULY 1945
DECEMBER 1944

lime is a deciduous tree; and in October the leaves are shed, each leaving a corky scar on the twig immediately below the axillary bud. By this time the outer part of the twig has acquired a hard corky covering, broken here and there by small areas of softer tissue. These areas are the **lenticels** and give the living tissues of the twig access to the air. After the leaves have fallen the twig has the appearance shown in Fig. 10, and it survives in a resting condition until the following spring. Then, each of the buds behave in the same way as the original bud, and hence the branching twig shown in Fig. 10 is produced. Thus, it is easy to see how the complex branching system of a tree is developed. The amount of growth per year depends partly on the size of the bud and partly on the quantity of food in the trunk and branches. Both of these depend on the conditions for food production of the previous summer. As a rule the most vigorous branches develop at the outside of the tree where the light intensity is greatest. More spindly growth is produced in the inner parts of the tree.

Roadside trees in towns are often lopped during the resting season, and, if this is done, the branches produced in the next spring and summer are abnormally long and luxuriant. Lopping removes the majority of the buds and so the whole of the food material stored in the trunk is available for the few buds which remain. Each bud has an abnormally large food supply, hence the luxuriant growth.

In the lime, flowers are produced on the normal shoots which develop from the buds, but in some trees, such as elm and ash, flower-buds and leafy shoot-buds are distinct. In these the flower-buds often open before the leafy shoot-buds. Many fruit trees and some forest trees, such as beech, are characterized by the production of shoots of very limited growth as well as the normal shoots of considerable growth. Such shoots are termed dwarf shoots, and they are often developed from the lower buds of a year's growth. In fruit trees leaves are usually present both on the long shoots and the dwarf shoots, but flowers are often confined to the dwarf shoots. When fruit trees are pruned the top part of the current year's growth bearing most of the vegetative buds is removed. This means

that more food is available for the vigorous development of the dwarf shoots which produce the flowers and fruit.

The tree habit has many advantages. If trees become firmly established they are the dominant plants of the neighbourhood; their extensive growth enables them to obtain very good supplies of food and light, and any herbaceous plant growing under a tree is severely handicapped as regards both food and light. In its wild state most of Britain would be natural forest. Our meadows, pastures, cornfields, potato fields only exist as such because man has cut down the original forest and has prevented the trees from becoming established. Any piece of neglected meadow is gradually dominated by shrubs, and later, as trees become established, it becomes a thicket.

INTERNAL STRUCTURE OF PLANTS

If we cut a very thin slice of a leaf (Fig. 11) and examine it in water under the microscope we find that it consists of a very large number of units called **cells.** The most obvious part of a plant cell is the bounding layer or **cell wall** which is made up of a relatively rigid material called **cellulose,** but actually the contents of the cell are much more important than the wall. Lining the wall is a granular jelly-like material, which is the all-important living substance **protoplasm.** In leaf cells there are oval green granules called **chloroplasts** embedded in the protoplasm and these contain the substance **chlorophyll.** The **nucleus** of a cell is a specialized part of the protoplasm. The central part of the cell is occupied by water containing various dissolved substances; this is the **cell sap.** The plant is made entirely of cells of one kind or another which were made originally at the growing points. At the growing points the cells are all alike and are completely filled with protoplasm. As growth takes place they enlarge by the taking in of water, and then further developments take place so that the mature cells are of several different kinds. A collection of cells of one kind is called a **tissue** and a mature plant consists of several different kinds of tissue.

The leaf cell described in the last paragraph forms part of

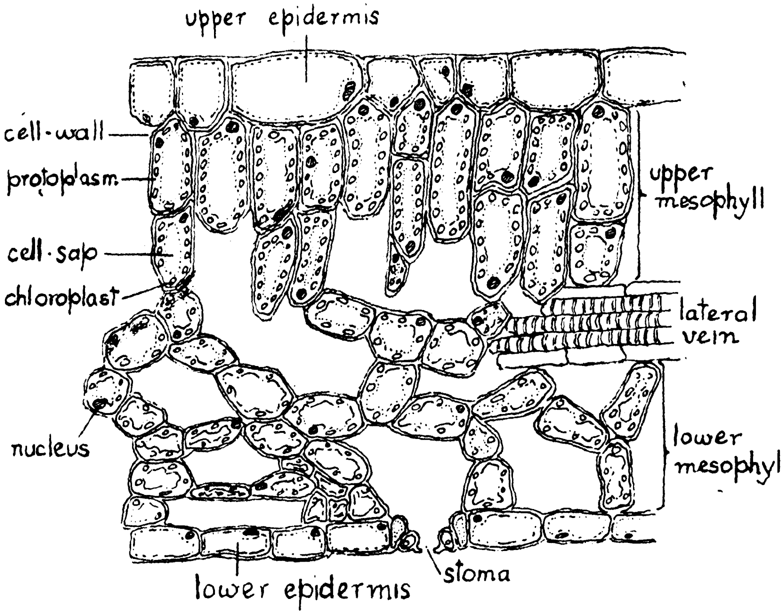


FIG. 11.—Section of a leaf.

the so-called **mesophyll tissue** of the leaf. This is permeated by veins and it has many air spaces. It is bounded above and below by a protective tissue called the **epidermis.** The outer walls of the epidermis cells are covered by a water-proof and gas-proof layer called the **cuticle**. There are occasional pores in the lower epidermis, each being bounded by a specialized pair of guard cells. The pore and its guard cells constitute a **stoma.** You can see these in surface view by examining the lower epidermis only (see Experiment 10, and Fig. 28).

Fig. 12 shows a thin slice of a marigold stem as it appears under a powerful lens. It is bounded by an epidermis and is filled with tissue somewhat similar to the mesophyll of a leaf; for convenience it may be called ground tissue. Embedded in the ground tissue is a ring of specialized strands; these are called **vascular bundles**, and are continuous with the veins of the leaf. The inner tissue of the vascular bundles is called

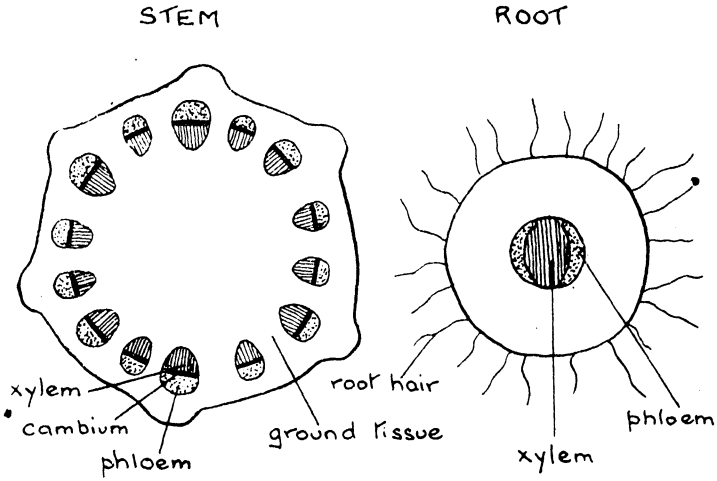


FIG. 12.—Sections of marigold stem and root.

xylem ; it has long thick-walled vessels which do not contain any protoplasm and are filled with water. The outer part of the vascular bundle is composed of long cells with dense contents called **phloem.** Between the xylem and the phloem is a zone of actively growing cells called the **cambium** which is continually forming new xylem inside and new phloem outside.

In the lime stem (Fig. 13) the xylem and phloem form a continuous cylinder with a layer of cambium between them. By the activity of the cambium the girth of xylem and phloem increases throughout the summer. The outer layers of the lime stem consist of an impermeable tissue called **cork**, and the girth of this continually increases by the activity of the cells under it. Hence the girth of the outer tissues keeps pace with the increasing girth within. At intervals, patches of soft permeable tissue are formed instead of cork ; these patches are the lenticels. The drawing on the right shows a lime stem in its third year of development. You will notice that the xylem shows zones ; this is because the cambium forms harder xylem towards the autumn, while in the spring and early summer it forms xylem of a more open texture. The compact xylem forms the annual rings which may be used to estimate the age of a cut branch or trunk.

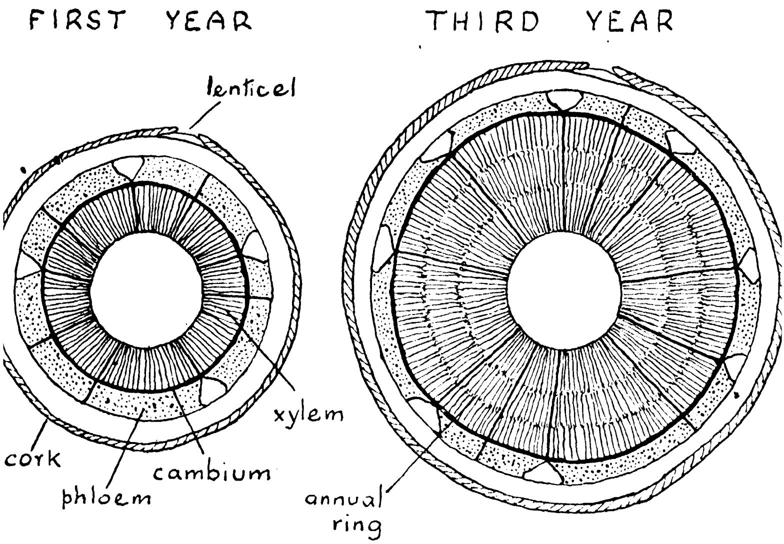


FIG. 13.—Sections of lime stems.

Fig. 12 shows a thin slice of a marigold root. Its outer layer of cells has specialized outgrowths or root hairs, and there is no cuticle. The xylem and phloem are differently arranged from those of a stem. Roots of trees have massive cylinders of vascular tissue similar to those of the stems of trees.

QUESTIONS

1. *In what form are the following planted: carrot, potato, tulip? Choose any one of these plants and draw its appearance (a) in the resting season, (b) in the active season.*

2. *What do you understand by vegetative reproduction? Describe how TWO of the following reproduce vegetatively: strawberry, mint, crocus?*

3. *Make a labelled diagram of the appearance of the twig of a named tree in winter showing two seasons' growth.*

4. *Answer the following:*

(a) What do you understand by the terms annual, biennial and perennial?

(b) In what sorts of situations do wild annual plants flourish? Give reasons.

(c) What are the advantages of the tree habit?

(d) Why are grasses such successful plants?

CHAPTER II

ANIMAL FORM

In this chapter we are going to learn about the bodily structure of a mammal. Cats, dogs, lions, tigers, cows, sheep, mice, rabbits and foxes are all mammals, for they are all furry, warm-blooded animals with a back-bone. Man is also a mammal, although his amount of hair is limited. Also, he moves about in an upright position instead of on all fours. When we are comparing man with the other mammals, it is convenient to imagine man as though he moved about in a crawling attitude on all four limbs. Then the various parts of the body are more easily comparable. We describe the head end of the body as **anterior**, the other end as **posterior**, the surface of the body facing the ground as **ventral** and the surface away from the ground as **dorsal**. The body of a mammal consists of a head, a trunk and two pairs of limbs; it is a very compact structure, without any straggling or branching. Such compactness of structure is essential in an animal, which has to move about from place to place; and it may be contrasted with the elaborate branching of a plant, which remains fixed in one place.

ANIMAL CELLS

Within the compact body of a mammal is a most intricate system of internal organs, and these organs are made of tissues which are much more specialized than plant tissues. The chief kinds of animal tissues are muscle, bone, cartilage, connective tissue, lining tissue (or epithelium) and nervous tissue. All of these consist of living cells. An animal cell consists of a mass of protoplasm containing a nucleus, but there is no cell wall surrounding it, and hence animal cells are more difficult to see under the microscope than are plant cells. However, if you scrape the inside of your cheek with your finger, and then examine the cells in the scrapings, you will see fairly

typical and relatively unspecialized animal cells of epithelium tissue (Fig. 14). Epithelium tissues make a lining for all the internal cavities, but all epithelium cells are not as simple as those of the cheek cells.

In **muscle tissue** the cells are considerably elongated and contain a particular kind of protoplasm, which is capable of changing its shape (Fig. 14). **Bone, cartilage** and **connective tissue** contain cells at intervals, separated by a ground substance which embeds them (Fig. 14). In bone, the ground substance is very hard and rigid, in cartilage, it is horny and extensible,

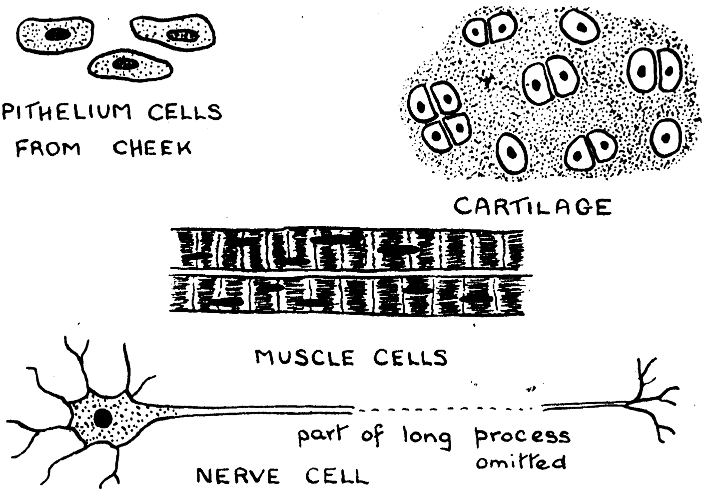


FIG. 14.—Animal cells.

and in connective tissue, it has a meshwork of interlacing fibres. It is true that the nature of the ground substance confers on these tissues their characteristic properties, but you must always remember that the living cells are the essential parts, for it is they which manufacture the ground substance. Cells of **nerve tissue** are irregular in shape and have a series of outgrowths, one of which becomes much longer than the others (Fig. 14).

Such are the cells of which we are made. There are many millions of these living units within each of us and the smooth

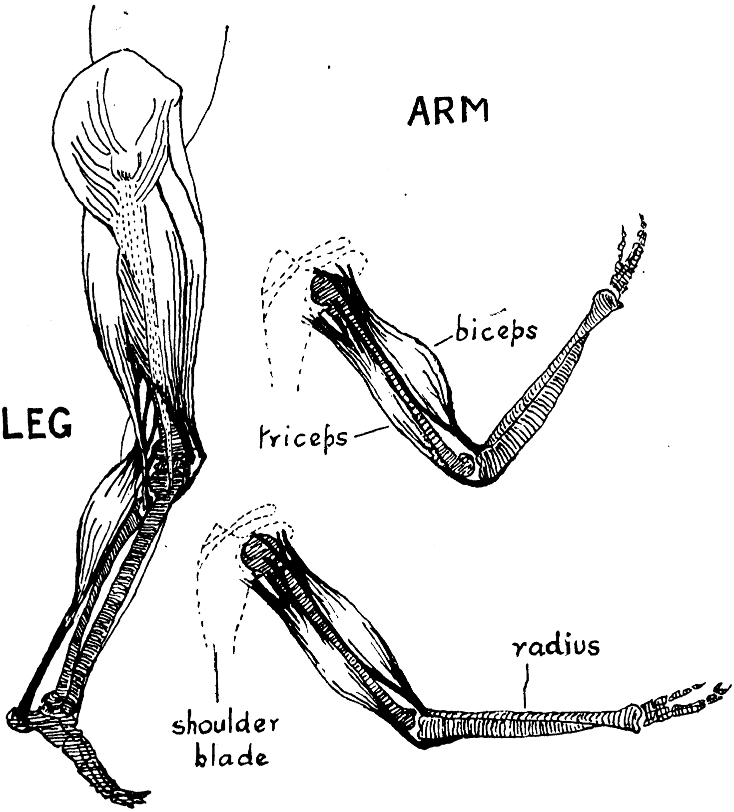


FIG. 16.—Some muscles of the leg and arm.

of shortening and thickening of muscles is called **contraction,** and you will realize that this is not a very good term since the volume of the muscle does not decrease.

THE TRUNK

The Trunk Wall.—The trunk is not a solid structure like the limbs, for it encloses a most important cavity in which the internal organs are contained. The trunk wall resembles the limbs in that beneath the skin it is largely made of muscles and bones. The back-bone (Fig. 17) is the supporting axis in the dorsal wall of the trunk. It consists of 33 separate

bones or **vertebrae** and the joints are formed by cartilage pads. These pads permit a certain amount of movement, so that the body is not poker-like and rigid. Our carriage depends partly on the position in which we maintain our back-bones. A normal correct posture depends on the training of the right muscles; if this training is neglected in youth, bad postures associated with spinal curvature develop. Hence the importance attached to posture at school and at home. Most mammals have more than 33 vertebrae, for their back-bones are extended into their tails. Each vertebra has a solid ventral part (the centrum) surmounted by a dorsal arch (Fig. 18). The arches of successive vertebrae make a long

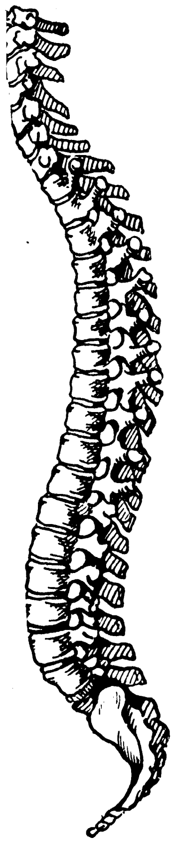


FIG. 17.—The vertebral column.

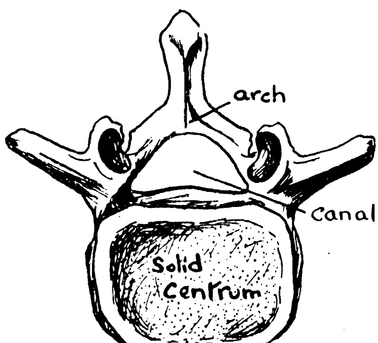


FIG. 18.—Lumbar vertebra—anterior view.

tunnel which houses the main nerve cord of the body, the spinal cord. From this are distributed branch nerves which make their exit from spaces between the vertebrae and are distributed to every part of the body. There are various projections on the vertebrae which serve as useful attachments for many of

organs removed. It will be seen that the **kidneys** are attached to the dorsal wall of the abdomen and that there is a tube, or **ureter**, leading from each kidney. These ureters lead into a hollow bag, or **bladder**, which communicates with the exterior. The figure represents a female animal and the **ovaries** are seen to be attached to the dorsal wall. Their tubes, or **oviducts**, pass through the cavity and accompany the bladder towards the exterior.

THE HEAD

The framework of the head is the skull, and this affords a bony protection to the brain and the major sense-organs—eyes, ears and nose. The deep cavities in the skull protect the eyeballs. The bones of the skull fit together tightly like the pieces of a jig-saw puzzle; the only movable bone being the lower jaw, which communicates by a normal joint on each side with the upper jaw. The brain is continuous with the spinal cord and it is essentially the headquarters of the body, from which all the parts are controlled.

In the mouth are the teeth, which are fixed by their roots in sockets of the upper and lower jaws. Fig. 23 shows a section of one of the front cutting or incisor teeth. The bony part of the tooth is called dentine, and this is supplied with food from the pulp cavity in the middle, which contains blood vessels and nerves. The exposed part of the tooth, the crown, is covered with resistant enamel. In each jaw there are four of these incisor teeth with very sharp cutting edges. Then there are two pointed canine teeth, one on each side of the incisors; these are suitable for tearing flesh. Beyond the canines are the molars, with large ridged crowns and several roots; these are the grinding teeth and there are eight or ten molars in each jaw. In human beings, the teeth do not do a great deal of work, for much of it has already been done by the knife and fork. We can appreciate the true value of the canine teeth if we watch a dog tearing flesh from a bone; of the molars if we watch a sheep or cow munching, and of the incisors if we watch a rabbit nibbling.

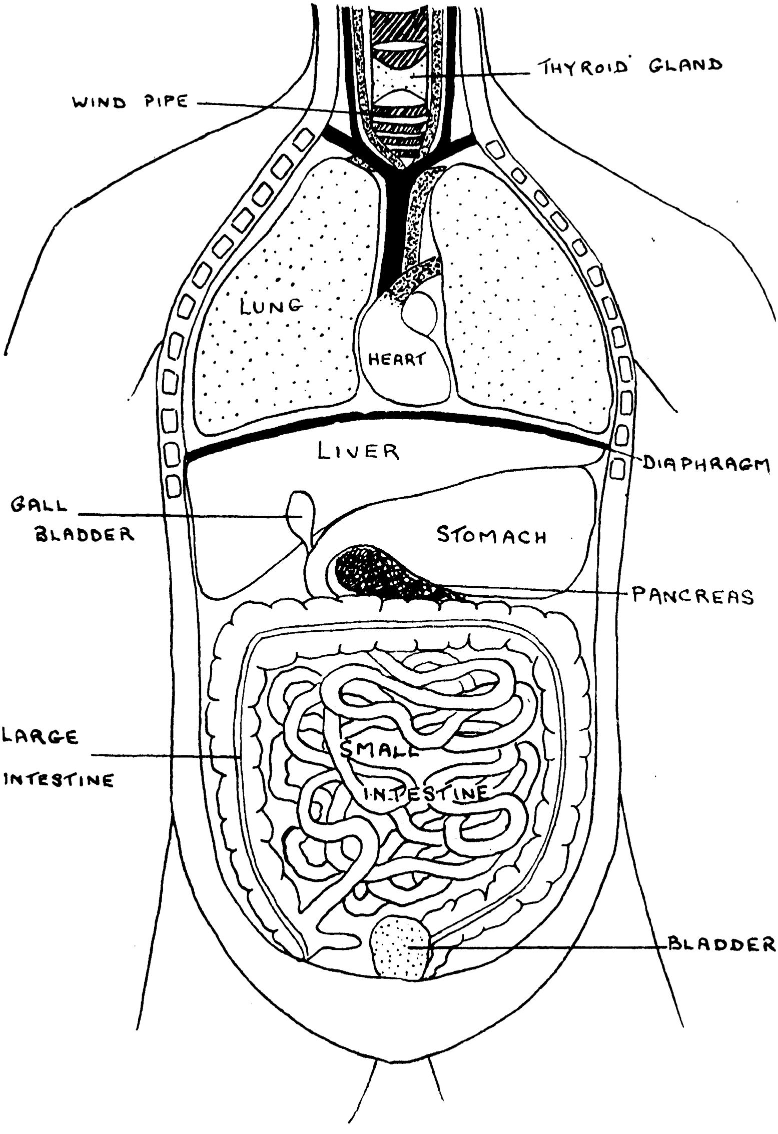


FIG. 20.—Trunk of man with ventral body wall removed.

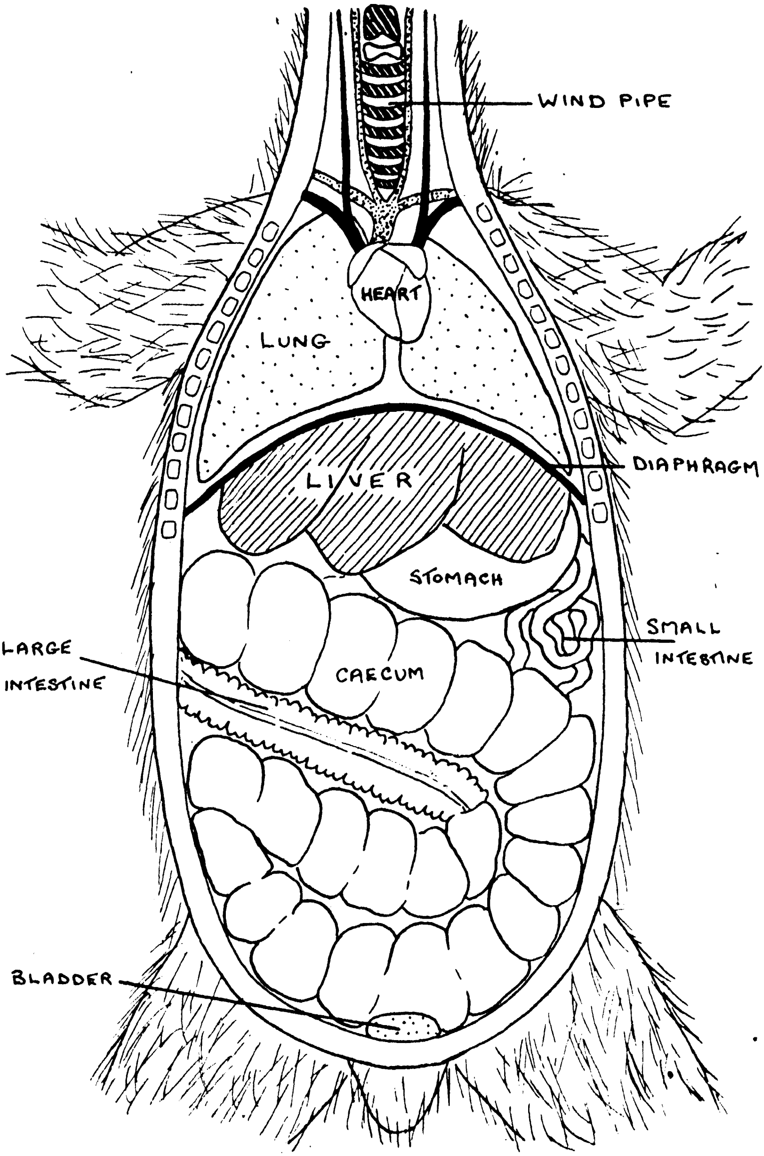


FIG. 21.—Trunk of rabbit with ventral body wall removed.

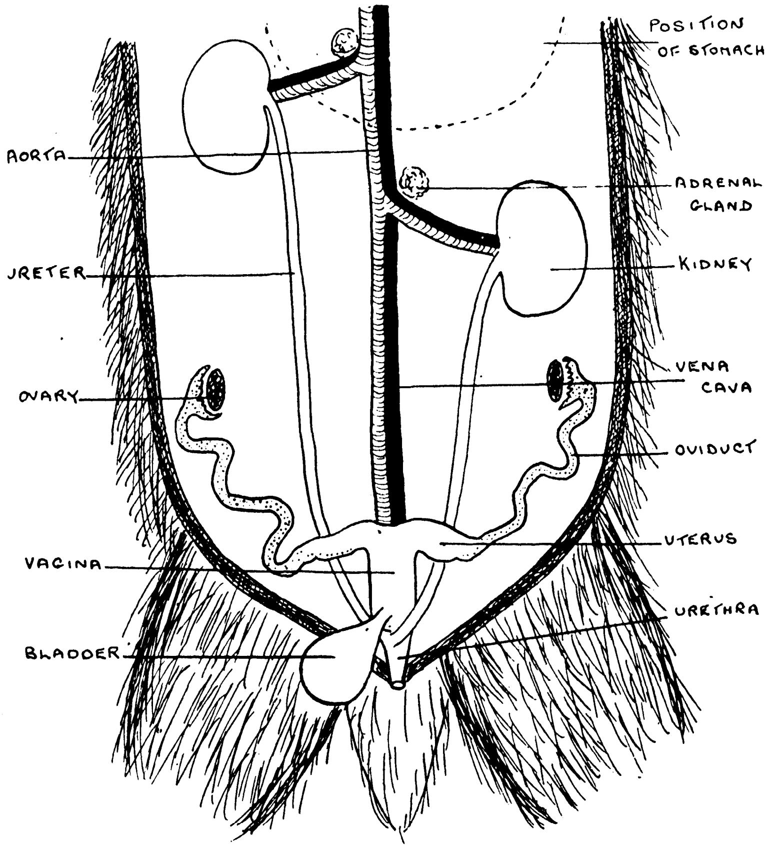


FIG. 22.—Abdominal cavity of female rabbit with digestive organs removed.

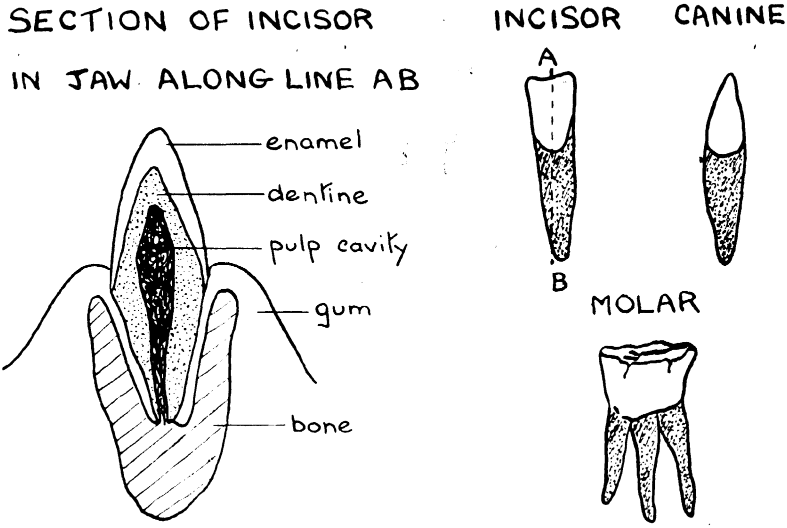


FIG. 23.—Teeth of man.

QUESTIONS

1. (*a*) *Describe as exactly as you can the position in the body of the following organs: diaphragm, liver, kidneys, heart.*

(*b*) *Name the chief parts of the alimentary canal of man. Explain how these are arranged in the cavity of the trunk, and account for the fact that, although the total length of the canal is* 33 *feet, it fits into a trunk of about two feet in length.*

2. (*a*) *What do you know of the structure and uses of the back-bone?*

(*b*) *Describe the position and use of the ribs.*

(*c*) *What is a joint? Why are joints of great importance?*

3. *By reference to* (*a*) *an epithelium cell,* (*b*) *a mesophyll cell of a leaf, give an illustrated account of the chief parts of an animal cell and a plant cell. What is the chief difference between animal cells and plant cells?*

CHAPTER III

SOIL

You do not need much knowledge of gardening to convince you that the soil is of far more importance to plants than a mere anchorage for their roots. It provides water and other essential materials for growth, and it is the business of the gardener and the farmer to see that soil conditions are as favourable as possible for the obtaining of these materials. Now soil is a complex mixture, and we can get some idea of the components of the mixture by the following experiment :

Experiment 1.—Put a handful of soil in a gas-jar, hold it in a sloping position and pour some distilled water down the side very gently. As the water percolates into the soil it drives out the soil air, which rises to the surface in the form of bubbles. Now fill up the jar with water, stir the contents vigorously and allow the contents to settle. Floating on the top of the water there may be small pieces of half decayed leaves and twigs. The bottom of the jar is covered rapidly with coarse particles which sink at once ; these are particles of sand. After about five minutes a sediment of much finer consistency starts to form on the top of the sand ; this is silt. The muddy liquid filling the gas-jar consists of the still finer particles of clay suspended in the water. If the gas-jar is left undisturbed for two or three days they also will sink, leaving a pale yellow solution containing the soluble substances of the soil. If you want to see these soluble substances, pour off some of the solution and evaporate to dryness.

SOIL PARTICLES

A quarry cutting teaches us several things about soil. First of all the ordinary dark soil extends for only a few feet. Below it is the lighter subsoil, which may extend to a considerable depth, and under the subsoil is rock. Both soil and subsoil have been derived from rock, and the soil particles are actually rock fragments. Soil particles have been gradually formed from rock by a process known as weathering. Without the weathering of rock there would be no soil and the earth's surface would be covered by one vast expanse of rocks.

Frost plays a large part in the breaking up of rocks. When water freezes it expands very considerably and, as we know from bitter experience in severe winters, the force of expansion is sufficient to burst pipes. Liquid water may trickle into the crevices in rock, and when it freezes, the force of expansion is sufficient to extend the crevices so that some of them may meet one another, thus detaching small pieces of rock. Apart from the action of ice, extremes of temperature may cause weathering more directly. Most rocks consist of several different kinds of material and, if these have unequal degrees of expansion and contraction, cracks may be formed. Rocks may also be weathered by the removal of the more soluble constituents, and sometimes chemical action may come into play, especially if part of the rock contains calcium carbonate. Rain water contains dissolved carbon dioxide. this gradually converts the insoluble calcium carbonate into soluble calcium bicarbonate, which is washed away, leaving a crack. Weathering sounds a very slow process, as indeed it is, but in time, by means of all these processes, the surface of the rock is covered by small particles among which a few lowly plants, such as mosses and lichens, establish themselves. When these die, they decay and their dark coloured remains are added to the particles. Meanwhile, weathering continues below and the soil layer deepens. Now we have the first true soil, for this consists not only of rock fragments but also of plant and animal remains in various stages of decay collectively known as **humus.** The dark colour of soil is due to the humus which permeates it throughout. In the sedimentation experiment even the sand was dark coloured because of the humus contained in it. Subsoil is always lighter in colour than the top soil because it does not contain any humus.

The nature of the rock fragments in a soil will obviously depend on the nature of the rock which was weathered. Sand is produced by the weathering of sandstone, quartz and granite, clay is produced by the weathering of shale, and limestone fragments are produced by the weathering of limestone rock. This sounds as though the rock particles in any one place should all be of one kind, and indeed we do speak of sandy soils,

limestone soils, clay soils, according to the predominating type of particle. But, since no rock consists entirely of one substance, the result is that a so-called sandy soil contains a certain amount of clay and silt and limestone, while a clay soil contains some sand, and so on. The most fertile soils are **loams** containing both sand and clay.

Now plants do not absorb the rock fragments of the soil, and it is of no significance to plants that sand is silicon dioxide while clay is a complex silicate of potassium and aluminium. The importance of the particles lies in their physical properties. They determine the texture of the soil into which the roots of the plants must penetrate. Sand particles are large and readily separate from one another; a sandy soil is very easy to dig and no clods are formed. On the other hand, the small particles of a clay soil tend to unite as large clods which are very difficult to dig. In a sandy soil it is easy to obtain a good tilth for seed planting, in a heavy clay soil this is much more difficult. The sizes of sand and clay particles have very important indirect effects on air, water and mineral salt supplies, all of which are essential for plants.

WATER AND AIR IN SOIL

Between the soil particles are spaces containing water and air. These spaces are penetrated by the root hairs (Fig. 24)

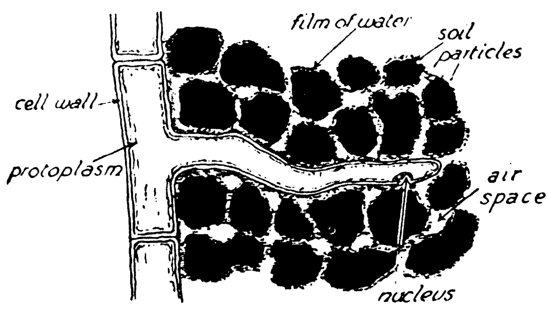


FIG. 24.

which use both the water and the air. During very heavy rain the soil spaces may be temporarily almost full of water,

but this drains away, leaving only films of water surrounding the particles. It is the films of water round the particles which are absorbed by the roots. Soils vary in their capacity to retain water as films round the particles.

Experiment 2.—Take two large funnels standing in measuring cylinders and plug each with a small piece of cotton wool. Into the first funnel put a layer of dry powdered sand of depth about 1 inch. Into the other funnel put the same quantity of dry powdered clay. Then pour into each 50 c.c. of water. Almost instantaneously water starts to drip into the measuring cylinder under the sand, for percolation is very easy. It may be an hour or more before the first drop emerges from the funnel containing clay. Allow the water to finish percolating through both soils and then measure the volume in each measuring cylinder, and from this deduce the volume retained by each soil. You will find that sand retains considerably less water than clay.

Clay soils have an enormous number of very small particles and hence the total surface area occupied by water films must of necessity be larger than in the coarse-grained sand. In addition to this, there is a definite attraction of water to the very minute particles, and we say that clay adsorbs water. Sandy soils are apt to be deficient in water content because of the amount lost by percolation. In all kinds of soil water is also lost by evaporation from the surface. In a garden on sandy soil the evaporation is sometimes prevented by covering the surface with straw or grass cuttings, and this process is known as mulching.

The soil atmosphere is an essential factor in the growth of plants, and good cultivation of soil will always take this into consideration. The soil atmosphere should have much the same composition as ordinary air, but sometimes, in compact soil, there is little opportunity for diffusion and the oxygen content may become deficient. One beneficial effect of digging is that it facilitates the interchange of gases between soil air and ordinary air. It is obvious that there is some relation between the air content of a soil and its water content, for the more volume taken up by water films the less room for air. A water-logged soil is harmful to plants, not because the water itself hurts them, but because the air spaces are all occupied

by water and the roots suffer from lack of air. Clay soils are apt to become waterlogged. You will begin to understand why a loam soil containing equal proportions of sand and clay is a fertile one, for it has adequate water and air content, whereas a sandy soil is often deficient in water and a clay soil is often deficient in air.

MINERAL SALTS

In Experiment 1, you found that the soil contains soluble substances. These substances play a very important part in plant growth as may be seen by the following experiment:

Experiment 3.—Cover two jam-jars with cardboard squares and in each square make a small circular hole and a slit (Fig. 25). Fill one jam-jar with soil solution (obtained as in Experiment 1) and the other with distilled water. Now choose a plant which will readily grow from cuttings (Tradescantia is particularly suitable) and cut off two vigorous shoots about three inches long. Make the cut at the level of a leaf. Remove all the leaves, except three at the top, and insert the cutting in the slit in each cardboard, keeping it in position with a pad of cotton wool. The cut surface of the stem should be below the liquid. Now put a glass tube through the round hole and tie a brown paper covering on the outside of the jam-jar. After a week or two you will see roots developing from the cut end of the stems. These roots can grow in the distilled water or soil solution provided there is an adequate air supply. The glass tube permits air to enter, but this is a very slow process, and it is just as well to blow air through the tube by means of a bicycle pump about once a week. After several weeks you will notice a marked difference in the growth of the two plants both in regard to root system and shoot system. The plant in the soil solution is much more developed and hence the soluble substances are of considerable significance.

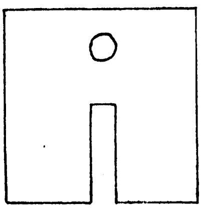


FIG. 25.

Chemical analysis of soil solution shows that the soluble substances are a mixture of compounds in which the following elements may be detected: magnesium, potassium, sodium, calcium, iron, arsenic, boron, chlorine, sulphur, nitrogen, phosphorus and others. The compounds are usually salts of the various metals and hence they are called mineral salts.

Sulphates, phosphates, nitrates, carbonates and chlorides are the chief salts. All the elements found in the soluble substances of soil are not necessarily used by the plants. In a later experiment (Chapter VII, page 77) we shall find out which of the above elements are essential. In the growing of crops the essential elements are gradually removed, and when the crop is taken away there is no possibility of the substances being restored to the soil again. Hence farmers and gardeners have to manure their land to restore the essential elements which have been depleted. The subject of manuring will be treated in Chapter VII, page 81.

In the natural state the soluble substances are found in the water films round the soil particles. Clay particles adsorb mineral salt molecules as well as water molecules, and, as a rule, the mineral salt content of a clay soil is good. In a sandy soil considerable wastage of mineral salts, especially nitrates, occurs by their being washed down to lower levels. Loam soils are able to adsorb mineral salts on the clay particles.

LIVING ORGANISMS IN SOIL

The soil is the home of several creatures which feed on plant roots (leather-jackets, wireworms, millipedes). Earthworms feed on decaying fragments of plants and animals, which they obtain by eating the soil itself. They benefit the soil because they eject the undigested residue of the soil in a very finely divided fertile condition. Moreover, the large number of burrows formed by the earthworms help to aerate the soil.

The soil is also the home of a vast population of microscopic organisms. We may convince ourselves of the existence of these by trying to grow them.

Experiment 4.—Soak 5 grammes of agar-agar in 250 grammes of water for two days. Then heat gently in a flask until it dissolves. Add about a teaspoonful of Bovril, then plug the mouth of the flask with a compact pad of cotton wool and heat it in a water-bath for at least four hours. This prolonged heating kills any living organisms contained in the liquid. The killing of micro-organisms in solutions and in apparatus is called **sterilizing.** Meanwhile, sterilize two Petri

dishes by putting them in an ordinary air oven for an hour. If you do not possess Petri dishes you can use two crystallizing dishes of different sizes, using the larger one as a cover for the small one. Now pour out some of the Bovril and agar mixture into each dish and cover at once. As cooling takes place the mixture sets in a firm jelly and, if sterilizing has been successful, the jelly should keep indefinitely without the appearance of any moulds. Take a piece of soil between forceps (which have been previously sterilized by heating) and rub it across one agar plate in the form of a cross. Cover again at once. Leave the other plate as a control. After a few days the cross is well marked by the presence of many round slimy areas. Each of these is a colony of many thousands of bacteria. If you examine some of the slime in a drop of water under a microscope you will see that each bacterium is a very minute little rod (see page 239, Fig. 115). Some of the colonies may have spherical bacteria instead of rod-like ones. Also, the size and shape of the rods may vary in the different colonies. On the agar plate also there may be several masses of ramifying threads which are the soil fungal moulds (see Chapter XIX). All this time the other control plate should be free of bacteria and moulds. Occasionally, you may find perhaps one or two isolated colonies developing if your sterilizing has not been quite perfect.

The organisms developing on the agar plate are those most favoured by the particular nutrient in the agar jelly, and they are not necessarily those which are most active in the soil. Both bacteria and fungi play a very important part in the soil, for they are responsible for causing decay. The whole subject of decay will be dealt with in Chapter VII, page 80. At this stage you may like to try an experiment to show that decay is due to living organisms.

Experiment 5.—Fill a Petri dish (or a pair of crystallizing dishes) with garden soil and put it into an air oven for at least four hours to kill all the living organisms. When it is cool moisten the soil with sterile water (made by boiling distilled water gently for about half an hour and then plugging the flask with cotton wool). At the same time fill another sterile Petri dish with ordinary moistened garden soil. Sterilize the surface of two iris leaves by wiping them with a piece of cotton wool soaked in methylated spirit and then rinsing in sterile water. Cut the leaves into small rectangles about one inch long, using a sterilized knife, and then bury the pieces in the sterilized soil and in the ordinary soil. After about three weeks the pieces of leaf in the ordinary soil will have started to decay while the pieces in the sterile soil are still intact.

HUMUS

Several times in this chapter the importance of decaying plant and animal matter has been mentioned. All soil contains a certain amount of this organic matter or humus which gives a dark colour to the soil. Soil without its humus content is quite a different colour.

Experiment 6.—Put some ordinary garden soil into a crucible and heat it strongly. The organic matter of the soil gradually burns to form carbon dioxide and water vapour, both of which escape into the air. The colour of the soil changes from dark brown or black to reddish brown or light brown.

Farmers and gardeners set great store by the humus content of their soils. Many gardeners add humus in bulk to their gardens by digging in leaf-mould. Humus has a spongy consistency and helps to lighten a clay soil by an increased number of air spaces. Moreover, humus material has great powers of adsorbing both water and mineral salts and thus humus will have very beneficial effects on a sandy soil. All natural manures, such as horse manure and hop manure, improve the humus content of the soil. In compost heaps vegetation is rotted down in order to form humus which may be added to the soil.

Let us summarize very briefly what we have learned about soil in this chapter. As far as plant growth is concerned the important constituents of the soil are water, air and mineral salts. The texture of the soil is also important since roots must establish themselves. The soil particles are of significance only because of the effect of these on texture and on air, water and mineral salt content. The chemical nature of the particles is of no significance. The humus of the soil has important properties of retaining both water and mineral salts.

In the Chemistry book of this series you will find other experiments on soil.[1]

QUESTIONS

1. *Suppose that you are undertaking the charge of a garden. What are the chief soil properties in which you would be interested? Describe*

[1] *Chemistry*, A. W. Wellings, uniform with this volume.

what you would expect these properties to be in (*a*) *a sandy soil,* (*b*) *a clay soil.*

2. (*a*) *What are the beneficial effects of deep digging in the autumn? In the process of digging why is it important not to bring the subsoil to the surface?*

(*b*) *Why is a water-logged soil harmful to growing plants?* (*See also Chapter IX.*)

CHAPTER IV

WATER IN PLANT AND ANIMAL LIFE

THE MAJOR SIGNIFICANCE OF WATER

All animal and plant tissues contain a surprisingly high percentage of water, for protoplasm itself has a high water content. The actual percentage of water in various tissues depends on the amount of cell-wall material in plant tissues or the extra cellular ground substance in animal tissues. A few examples are as follows: lettuce 94 per cent., wood 25–50 per cent., blood plasma 90 per cent., bone 22 per cent., muscle 75 per cent. The average water content of the human body is 59 per cent., and that figure applies to everybody, to geniuses, criminals and saints, as well as to ordinary human beings such as ourselves.

Apart from being an actual component of the tissues, water plays an essential part as a solvent. Food materials can only be transported in animals and plants in a dissolved state, and similarly, waste materials formed in the tissues can only be removed in solution. Also, all the complex reactions which take place in the protoplasm must take place in solution.

Plants have two special uses for water. They use it as one of the raw materials from which they make food (see Chapter VII). Moreover, the pressure of water inside the plant cells gives a certain amount of rigidity to the plant, and this is of particular importance in herbaceous plants which have very little mechanical tissue to support them.

Later in this chapter we shall see that both plants and animals evaporate water from the surface of their bodies and that this has a cooling effect.

HOW THE MAMMALIAN BODY IS SUPPLIED WITH WATER

The mammal has blood which acts as a very efficient means of transport, and all the living tissues are supplied with water

by means of blood. Water, together with digested food, passes into the blood from the small intestine (see Chapter VIII, page 96). Many mammals, including ourselves, drink liquid water or beverages containing water. Some mammals rarely drink any liquid and rely for their water on the vegetables they eat. A rabbit must derive all its water from greenstuff.

The water content of the blood plasma is approximately 90 per cent. This constant value is maintained by the excretion of excess water from the sweat glands, lungs and kidneys (see Chapter X). As water evaporates from the sweat glands it requires latent heat which is obtained from the body itself and hence evaporation of water cools the body.

HOW THE PLANT BODY IS SUPPLIED WITH WATER

Absorption of water.—Plants obtain their water supply from the soil. The branched roots extend in all directions and the surface area of all the young roots is very much increased by the presence of the root hairs. These are in intimate contact with the soil water films (see Fig. 24) and are responsible for the actual absorption. We shall understand how absorption takes place with the help of an experiment.

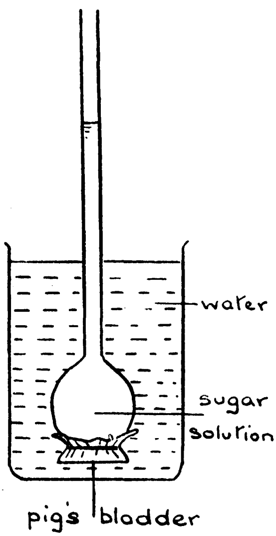


FIG. 26.

Experiment 7.—Stretch a piece of pig's bladder across a thistle funnel and tie it firmly in position. Dilute golden syrup with water until it pours easily and then fill the funnel (but not the stem) with the liquid. Support the funnel in clamps in a beaker containing water which is at the same level as the level of the syrup (see Fig. 26). After a few hours it is obvious that water is passing into the thistle funnel, for the level of the liquid rises and usually overflows over the top of the stem.

In this experiment the pig's bladder is a membrane separating the water and the sugar solution. There will be a tendency for sugar molecules to go through the membrane into the

water, and for water molecules to come into the funnel to dilute the sugar solution. Now pig's bladder is a special kind of membrane, because it will allow water molecules to pass through it but not sugar molecules; it is said to be **semi-permeable.** Hence, water passes into the funnel and rises in the stem. The column of liquid in the stem is being supported against gravity and the liquid continues to rise until no more can be supported. The passage of water into a solution through a semi-permeable membrane is called **osmosis**, and the pressure which supports the extra column of liquid is called **osmotic pressure.**

You will be wondering what connection there can be between the experiment with the thistle funnel and a root hair. The protoplasm of the root hair is a semi-permeable membrane comparable with the pig's bladder. The cell sap is a sugary solution, although it is much more dilute than the golden syrup used in the experiment. The soil water films correspond to the water in the beaker. Water enters the root hair by osmosis. There is no tube attached to the cell and the extra water is accommodated by the stretching of the cell. Now the cell wall is of very limited extensibility and exerts an inward pressure as soon as it is stretched. The osmotic pressure has to overcome this inward pressure and the water will be absorbed by the root hair as long as the osmotic pressure is greater than the wall pressure. As the cell becomes more and more stretched the wall pressure increases until it is as great as the osmotic pressure. Just as there is a limit to the amount of the rise in the thistle funnel there is also a limit to the amount of water absorbed by a cell. When the cell wall is fully stretched so that no more water can pass in we say that the cell is **fully turgid.** If the cell wall is not fully stretched, then the cell has a certain water-absorbing power determined by the difference between its osmotic pressure and the wall pressure.

So far we have only considered the passage of water into the root hairs. The inner root cells in contact with the root hairs will suck water from them provided their water-absorbing power is greater than that of the root hairs. The withdrawal

of water from a fully turgid root hair leaves it with a certain water-absorbing power enabling it to take in more water from the soil. Meanwhile, the cells in contact with the root hairs have parted with some of their water to their neighbours, hence their water-absorbing power again becomes strong enough to take further water from the root hair. So the process of osmosis from cell to cell goes on, the inner root cells absorbing from the outer cells, the outer cells from the root hairs and the root hairs from the soil.

It is not possible to measure directly the amount of water absorbed by a plant growing in the soil, but we can determine the absorption of a small uprooted plant.

Experiment 8.—Take two measuring cylinders containing water and into one put a groundsel or marigold plant so that its roots are submerged. Cover the surface of the water in both cylinders with olive oil. This stops direct evaporation of the water. As the roots of the plant absorb water the level in the measuring cylinder falls. Unless there are marked changes in temperature the level in the control measuring cylinder remains the same.

Transpiration in plants.—The water absorbed by the roots is transported to every part of the plant and, since plants have no circulatory system, it is difficult to understand how this transport is achieved. Osmosis alone from cell to cell would take too long. A well-grown elm is 100 feet high and the leaves of its topmost branches must be adequately supplied with water. The raising of water to this level against gravity is indeed an impressive feat. We shall be able to understand better the problem of raising water if we enquire first into what happens to the water when it reaches the top of a plant.

The making of new protoplasm at the growing points requires water, for protoplasm has a large water content. All the cells of the plant require water in their cell sap, and we have seen that the outward pressure of this water on the cell walls makes the cells turgid and confers a certain amount of rigidity on the plant. A little of the water undergoes chemical change in the making of plant food. However, most of the water absorbed by the roots does not remain in the plant but escapes from the leaves in the form of vapour. The evaporation of

water from a plant is called **transpiration**, and it may be demonstrated by a simple experiment.

Experiment 9.—Take a cut leafy shoot and put the end in a jar of water. Cover the surface of the water with oil to stop direct evaporation, and put the jar on a glass plate covered by a clean bell-jar. Put plasticine round the join between bell-jar and plate to prevent the escape of water vapour. Instead of a cut shoot you can use a potted plant, such as a geranium, but you must prevent direct evaporation from the soil by wrapping the pot in rubber sheeting, which is tied round the base of the shoot (Fig. 27). You should set up a control experiment containing either a jar of water with oil on the top or a pot of soil covered by rubber sheeting. After several hours, the sides of the bell-jar enclosing the plant are covered by drops of water, while the bell-jar of the control experiment is still quite clear. You can test the drops with anhydrous copper sulphate, which turns blue in contact with water. The water must have evaporated from the plant and condensed on the sides of the bell-jar. By enclosing the plant in a bell-jar the air round the plant soon becomes saturated with water vapour so that condensation takes place readily. In the open air there is no condensation and it is much more difficult to demonstrate transpiration.

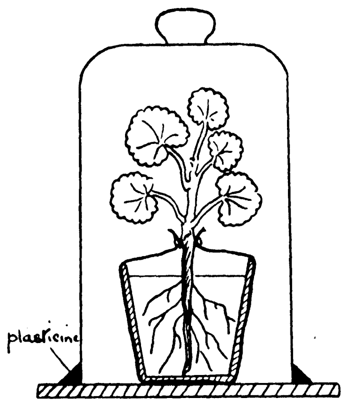


FIG. 27.

It is possible to demonstrate transpiration in single leaves.

Experiment 10.—Prepare some cobalt chloride solution (5 per cent.) and dip in it some pieces of filter paper and allow them to dry first in the air and then over a bunsen burner or in a warm oven. When quite dry, cobalt chloride is anhydrous and blue. It takes in water vapour and becomes pink. Dry two glass slides thoroughly and make a low plasticine rim round one slide. Put a piece of blue cobalt chloride paper on this slide, put the privet leaf on it, then another piece of blue cobalt chloride paper and finally put the other slide in position, pressing it down on the plasticine (Fig. 28). As water evaporates from the leaf the cobalt chloride paper turns pink. You will find that the paper in contact with the underside of the leaf turns pink first, showing that the most water vapour is lost from the under surface. This result is related

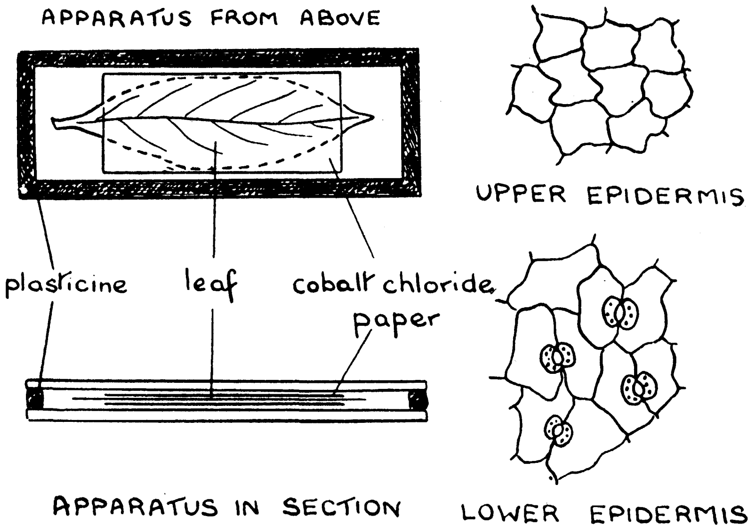


FIG. 28.

to the number of stomata on upper and lower surfaces. Put the privet leaf on a slide, upper surface upwards, and with a sharp knife scrape away all the tissues in one section until the lower epidermis is left. Cut this out and mount it in water under a cover glass. Now turn the leaf over and scrape away all the tissues from one patch of the leaf until only the upper epidermis is left. Cut this out and mount it in water under a cover glass. When you examine the two pieces of epidermis you will find many more stomata in the lower epidermis than in the upper epidermis. Evidently the greater number of stomata on the lower surface account for the greater transpiration from this surface. It is possible to carry out this experiment on a leaf which is still attached to the plant, if the slides are supported. If larger leaves than privet are used, larger glass plates are required. Hydrangea leaves placed between gas-jar covers give good results, but it is more difficult to isolate the epidermis.

The extent of transpiration.—In Experiment 9 you may have been surprised at the amount of water which condensed, and you may be interested to find out exactly how much water is transpired by a plant. It is not possible to estimate this by putting a plant under a bell-jar, for the air in the bell-jar is soon saturated with water vapour and then evaporation ceases. The plant used must be left in ordinary air, and you can

estimate the amount of water lost by weighing the plant at intervals.

Experiment 11.—Take a potted geranium and wrap up the pot and soil in rubber sheeting. Use as a control a pot of soil tied up in rubber sheeting. Weigh both to the nearest gramme or half-ounce, and leave them to stand on the laboratory bench. Weigh them again daily, when you will see that the weight of the control remains the same, while the weight of the plant decreases. Except for a small fraction, all this loss in weight is due to transpiration. You will find that quite a small plant loses 5 grammes a day. It is possible to do the experiment with a cut leafy shoot instead of a plant by using a jar of water and covering the surface with oil.

The experiment may be repeated to find out the effect of various external conditions on transpiration. Four similar potted plants or similar cut leafy shoots with the same number of leaves are set up as above and are weighed daily to see if the rate is approximately the same under laboratory conditions. Then one plant is put near an electric fan, another is put under a bell-jar lined with wet blotting-paper, a third is put out of doors in a sheltered hot sunny place and the fourth is left in the laboratory. By weighing the plants daily and comparing the rates of loss with the plant in the laboratory as a standard you will find that moving air (caused by the electric fan) increases transpiration, high humidity (under the damp bell-jar) reduces transpiration almost to zero, while the raised temperature (in the hot sunshine) increases transpiration.

These experiments are on a very small scale, but they give us some idea of the amount of transpiration per leaf. By counting the number of leaves on your small plant or shoot you can calculate the transpiration from a larger plant of the same kind with a greater number of leaves. Admittedly the estimation of the number of leaves on a large tree sounds a formidable task, but you can get an idea of the total if you take the trouble to find out the number on one of the branches. By calculations such as these it has been found that a sunflower plant loses over a pound of water on a hot day, while an average sized birch tree loses 900 lb. Trees play quite a large part in contributing to the water vapour content of the atmosphere. This water has come from the soil and it may go back to the soil again as rain.

Conditions Influencing Transpiration.—Look again at Fig. 11, which shows the internal structure of a leaf, and you will

understand better how transpiration takes place. Water evaporates from the mesophyll cells into the intercellular spaces. These spaces are in contact with the ordinary air via the stomata, and hence water vapour will diffuse out through the stomata as long as the intercellular spaces have a higher humidity than that of the ordinary air. The evaporation of water from the mesophyll cells uses latent heat and has a cooling effect on the plant.

Hence, transpiration is a process of evaporation, and in Experiment 11 you found that it is influenced by the same external conditions as influence evaporation. It is favoured by dry air, raised temperature and moving air, while it is retarded by high air humidity, lowered temperature and very still air. External conditions are not everything, for the total leaf area of the plant has a very big effect. Moreover, transpiration depends on the actual water content of the leaf. If this is deficient, the turgidity of the cells is considerably decreased, and the intercellular spaces are no longer saturated with water vapour, hence transpiration will decrease. Also, as the leaf becomes short of water, the guard cells of the stomata lose their turgidity and meet together, thus closing the pores and preventing further loss of water.

The Passage of Water through a Plant.—Now we must face the problem of how water is transported from the root hairs to the leaves. It is possible to follow the route of the water from the roots to the leaves by using coloured water.

Experiment 12.—Put some marigold or groundsel plants with their roots in water coloured by eosin or red ink. After a few hours the veins of the topmost leaves are coloured red, and if you cut sections of the stem at various levels you will find red staining in the vascular bundles. Examination of thin sections under the microscope will show you that it is the xylem part of the vascular bundles which is stained. The xylem becomes stained before the surrounding tissues, and hence it seems that the xylem is the quick route for water transport.

It will be remembered that the vascular bundles form a continuous system extending from roots into stems and out into leaves. Living tissues in the stems and leaves are supplied with water from the nearest xylem. Now xylem tissue

consists largely of long, woody, pipe-like vessels which are very suitable for the passage of water provided a force exists to make the water move upwards. This force is provided by transpiration. Let us carry out an experiment to show that a transpiring shoot can cause movement of water.

Experiment 13.—Figure 29 shows a piece of apparatus called a potometer. To fill it with water open the clip A and allow water to run out at the end of the capillary tube. Then, close the end of the capillary with your finger and allow water to overflow from B while you insert

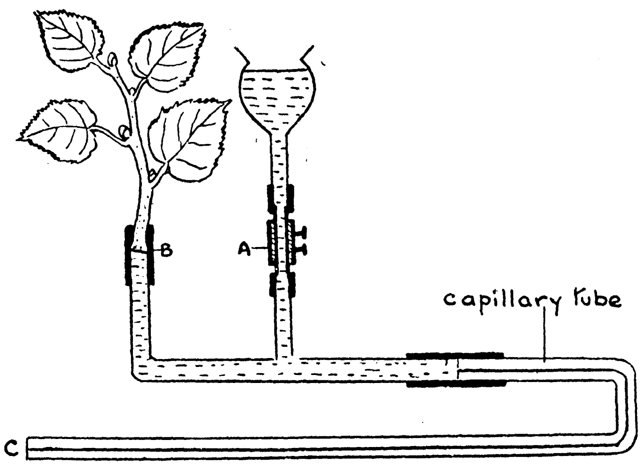


FIG. 29.—Potometer.

the cut end of a leafy shoot into the water. Then close clip A. As the leaves transpire more water is absorbed by the cut end of the stem and hence water is dragged along towards B. You will see this occurring by the gradual movement of an air column along the capillary tube. The more rapid the transpiration the faster the air column moves along the capillary. It is possible to vary the rate of transpiration in the shoot and to see the effect on absorption. Thus, if the apparatus is placed near an electric fan, the air column moves along more quickly, while, if the shoot is enclosed inside a bell-jar lined by damp blotting-paper, the movement of the air column is brought practically to a standstill.

Transpiration is a suction force acting from above downwards. As the mesophyll cells evaporate water into the

intercellular spaces they lose a certain amount of turgidity and so absorb water from their neighbours. These absorb from their neighbours and so the process of sucking water from cell to cell goes on until the xylem vessels of the leaf veins are reached. The cells abutting on the xylem remove water not from a closed compact cell but from an extensive system of pipes. As water is removed from the top ends of this system the remaining water goes into a state of tension, and to relieve this tension water will be sucked into the lower end of the system from the root cells. Hence the withdrawal of water by transpiration means that water columns move up the xylem vessels and that more water is absorbed from the root cells, which in their turn absorb from the soil. This movement of water through a plant is often called the transpiration stream. In the transpiration stream an adequate supply of dissolved mineral salts is carried into the plant (see Chapter VII, page 80).

Wilting.—The maintenance of an adequate water supply depends on the replacement of the transpired water by absorbed water. However, transpiration is not always balanced by absorption. In dry periods, when the soil water films are very thin, there are considerable forces, such as adsorption, tending to keep water in the soil, and then absorption by the roots decreases and may cease altogether. Under these circumstances the mesophyll cells cannot replace the water which they have lost by evaporation and gradually their turgidity decreases. If water loss continues the leaves droop because they are no longer supported by the turgidity of the cells. This process is called **wilting**, and you must understand that there is a gradual transition from full turgidity to perceptible wilting. Often the stomata close before there is perceptible wilting and this reduces transpiration so much that the low rate of absorption is adequate to maintain reasonable turgidity.

To maintain plants in a healthy condition we must not allow them to wilt, for a wilting plant passes only too readily into an irreversible withered condition. Wilting may often be prevented by curtailing transpiration. Thus, the best method of collecting wild flowers is to carry them in a tin lined with

wet blotting-paper. Cut flowers in water sometimes wilt because the xylem vessels at the cut ends of the stems have been blocked up by air bubbles or gummy exudation. To prevent this happening cut fresh surfaces to the stems, preferably under water.

Gardeners are often faced with the problem of preventing wilting. All transplanted plants are liable to wilt because the transplanting process is bound to damage the delicate root hairs. Uprooted plants are often transplanted by a process of 'puddling'. A hole is dug and filled with water, and soil is worked into the hole until the mud has the consistency of thick cream; then the roots of the transplant are inserted into this mud and the whole plant is kept firmly in position by pressing fresh soil round the base of its stem. This ensures an excessive water supply to compensate for the decreased root hairs. With transplants of particular value it is as well to shield the shoot system from hot sun by covering with a flower-pot for the first day or two until the damaged root hairs have been replaced by new ones. When you are growing plants from cuttings it is even more essential to prevent wilting, for a cutting has no roots at all. Cuttings are usually put into soil in pots or boxes which can be kept in a sheltered position. Also, the number of leaves per cutting is reduced to a minimum in order to cut down transpiration. Only when the cuttings have successfully developed roots are they transplanted into the open.

Root Pressure.—Our explanation of the passage of water through a plant is that it is dragged up by the force of transpiration. This explanation does not account for the exudation of liquid from the cut end of a shoot in early summer. This exuding indicates the existence of a force which pushes from below and it is called root pressure. The explanation of root pressure is unknown.

Experiment 14.—Take a vigorous potted plant, such as a fuchsia, in May, and put it in a bucket of water. Cut off the main stem to within two inches of soil level. Fix on a rubber tube while still under water and attach this to a long glass tube. Pour water into the top of the glass tube until it is just visible above the rubber. Now remove

the whole from the bucket and stand it on the bench. In a day or two you will see that the level of the water is gradually rising. There are no leafy shoots to exert a suction from above, and it is obvious that the water must have been pushed up from below.

QUESTIONS

1. *Describe the root system of a plant, and show how it is brought into intimate contact with the water of the soil. Explain how water passes into a root. (See also Chapter I.)*

2. *What sequence of events causes plants to wilt? Why are (a) cuttings, (b) cut flowers, (c) transplants particularly liable to wilt? Discuss measures for preventing wilting in (a), (b) and (c).*

3. *Answer both parts:*

(*a*) *Four potometers, A, B, C and D, were set up in the laboratory containing similar shoots, each with the same number of leaves. A was left alone, and the rest were treated as follows: B was put near an electric fan, in C the shoot was surrounded by a bell-jar lined with damp blotting-paper, and in D all the leaves of the shoot were cut off. Describe and explain the results you would expect if you took readings from all four potometers. (No drawings of apparatus are required.)*

(*b*) *What are the chief uses of transpiration to plants?*

CHAPTER V

CIRCULATION OF BLOOD

USES OF BLOOD

Everybody has some idea of the importance of the ever circulating blood stream. Without blood the life of a mammal would be impossible, and in fact the criterion of death is the cessation of the heart-beat. All living tissues must be supplied with water, food and oxygen by the blood. In the activities of the tissues various waste materials are liberated. Of these, carbon dioxide and a nitrogenous material called urea, are the chief. The waste materials are removed by the blood and carried to the places where they are ejected from the body. We are all familiar with the terms 'warm blooded' and 'cold blooded'; actually, the blood is not a generator of heat, but it does act as a distributor of heat throughout the body. In Chapter XI, page 144, you will learn that the activities of the body are partly determined by certain chemical regulators or hormones, and these are distributed throughout the body by the blood.

The blood is the gateway to the tissues, and we cannot be harmed or, for that matter, benefited by any substance unless it can gain access to the blood. If your tissues require a certain medicine the doctor must be sure to give it to you in a form which can be absorbed into your blood. Occasionally, when people are very ill, they are fed by injecting sugar directly into the blood. In a similar way various medicines may be injected directly into the blood. Bacteria and viruses causing disease cannot harm you unless they can gain entrance to the blood. The harm which they do if they do gain entrance to the blood is explained in Chapter XIX, page 240.

COMPOSITION OF BLOOD

Corpuscles.—Now let us find out the composition of this all-important liquid. Strictly speaking, it should be called a

tissue and not a liquid, for it contains cells called **corpuscles.** If you want to see the corpuscles you must examine some blood under a microscope. Shake your hand and then bind a duster tightly round the wrist. With a sterilized needle prick the skin at the root of the nail and transfer the blood to a watch-glass containing 1 per cent. solution of sodium chloride. Mount a drop of the diluted blood and examine it as quickly as possible. You will see hundreds of flat disc-shaped cells, which are the red blood corpuscles. They look yellow rather than red, and as you examine them they will become very irregular in shape ; this is due to the action of the mounting solution. In water as a mounting medium, the distortion is much more pronounced, and, in fact, we use sodium chloride in order to imitate the liquid part of the blood and prevent distortion as far as possible. Among the red blood corpuscles are a few larger, more granular, colourless structures which are the white blood corpuscles. Now look at both red and white corpuscles in a specially prepared stained film of blood. In the making of this preparation the corpuscles were killed and fixed in their original shapes.

The red blood corpuscles are not perfect discs ; each resembles a flat bun which has been pushed in slightly in the middle (see Fig. 30). Inside the colourless envelope is a solution containing red **hæmoglobin.** This has a great affinity for oxygen, with which it combines to form **oxyhæmoglobin,** and the red blood corpuscles are thus the oxygen carriers of the body. There are five million red blood corpuscles per cubic millimetre of blood, and, since there is about a gallon (4 litres) of blood in the human body, the total number of red corpuscles in the body is a truly colossal one. It is no wonder that our tissues are efficiently supplied with oxygen when there is so great a surface area of corpuscles avail-

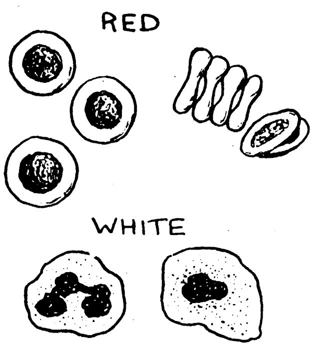


FIG. 30.—Corpuscles of blood.

able for carrying it. The red blood corpuscles are also partly responsible for carrying away waste carbon dioxide from the tissues.

The white corpuscles are larger than the red ones; on the average there is one white blood corpuscle to every 500 red, and hence there are 10,000 of them per cubic millimetre of blood. They are of various kinds and some of them are irregular in shape. Unlike the red blood corpuscles, each white corpuscle has a nucleus. The protoplasm of the corpuscle is capable of changing its shape by flowing out into projections. In making these streaming movements the protoplasm may engulf small particles which are used as food. The particles engulfed by the white blood corpuscles include also any foreign organisms, such as bacteria, which may be in the blood stream. Thus, the white blood corpuscles are a useful means of preventing disease. They are particularly useful in this respect at the surface of a cut. It seems that there is some substance produced at a cut surface which attracts the white blood corpuscles; at all events they are present in much greater quantities than in normal blood, and here they feed on any bacteria which may be on the cut. They do not necessarily destroy every single bacterium; sometimes infection takes place through a cut in spite of the activities of the white blood corpuscles. It is just as well to put an antiseptic on a cut instead of relying entirely on the white blood corpuscles.

Plasma.—The liquid part of the blood is called plasma. It is a pale yellow liquid containing approximately 90 per cent. water and 10 per cent. solids. The solids consist of proteins, sugar, nitrogenous waste in the form of urea, and certain salts including the chlorides of sodium, magnesium and calcium. It is the transport medium for water, dissolved food, hormones and urea.

One of the plasma proteins called fibrinogen plays an important part when blood escapes from a cut and clots. Like the other blood proteins fibrinogen is a soluble substance, but, on the surface of a cut, it is converted into an insoluble protein, fibrin, which forms interlacing strands. In the network of fibrin strands corpuscles and the rest of the plasma are en-

meshed. The formation of a clot of blood at a cut prevents the continued escape of blood ; if blood did not clot we should be in danger of bleeding to death from every minor injury. Certain unfortunate people do run this risk, for their blood has no power of clotting.

EXCHANGES OF MATERIALS BETWEEN BLOOD AND TISSUES

The heart pumps the blood through a system of closed vessels and the smallest of these, the capillaries, permeate every organ in the body. It is possible to see the capillaries under the microscope in the transparent webbing tissue between the toes of a frog's hind feet. A frog should be lightly chloroformed by holding cotton wool soaked in chloroform over its nostrils until it ceases to move. Then it is fastened to a glass block with a wide bandage. One of the hind legs is stretched out gently and the foot is arranged over a cork with a circular hole in it. Pins are put through the toe-nails to keep it in position. The cork is put on the stage of a microscope and the glass block is supported near it. Now the microscope may be focussed on the transparent webbing between the toes. It is necessary to keep the cotton wool soaked in chloroform handy, and if there is the least sign of movement it should be applied to the nostrils. Under the microscope you will see a network of channels (Fig. 31) along which there is a constant hustling of blood corpuscles. You will get rather an exaggerated idea of the rate of blood flow, for you have magnified the distance but not the time. The

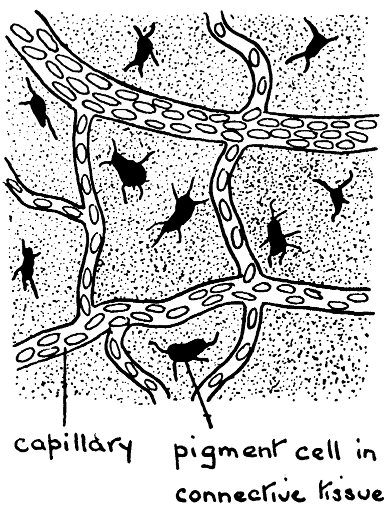


FIG. 31.—Capillaries in the web of a frog's foot.

actual rate of blood-flow in capillaries is something like 1 millimetre per second. You will notice that the red blood corpuscles of the frog are oval instead of disc-like.

In the narrowest capillaries the red corpuscles must travel in single file. All capillaries have very thin walls through which the liquid contents of the blood can leak out as **lymph**. All living tissues are bathed in lymph which acts as a 'middle man', or carrying medium, between the blood and the tissues. Via the lymph the tissues obtain their supplies of food, water and oxygen, and, via the lymph also, waste products are removed from the tissues. Lymph does not represent a permanent leakage of plasma from the blood, for it is ultimately collected in lymph vessels which gradually unite with one another and communicate with one of the great blood vessels of the neck. All the lymph which has leaked out of the blood is ultimately restored to it so that the supply of lymph bathing the tissues is continually being renewed.

The activity of every organ depends on the capillary circulation. The calibre of the capillaries can be altered both by nervous impulses and chemical controllers, and, in a resting organ, a number of the capillaries are so much contracted that no blood is flowing through them at all. When the organ is active all the capillaries are in action and they dilate so that there is a much increased blood flow to the organ. Thus, when the body is hot, the skin capillaries dilate. The outward sign of this is the flushing of the skin.

THE LARGE BLOOD VESSELS

Arteries.—Blood is pumped from the heart into arteries. The artery supplying each organ branches repeatedly until its ultimate branches are continuous with the capillary network. The larger arteries have very thick muscular walls and they have to withstand a large pressure of blood. At each heart-beat a considerable amount of blood is pumped into the arterial system, then there is a slight pause before the next heart-beat. The result of these alternating beats and pauses is that the blood flows through the arteries in a jerky fashion, the accelerated gushes of blood corresponding to each heart-

beat. If an artery is cut the blood gushes out with considerable force in a series of spurts. Arterial bleeding from a wound is a serious matter, for the blood is escaping much too forcefully for there to be an opportunity of a clot forming over the wound. If you have been to First Aid Classes you will have learned how to stop arterial bleeding by exerting pressure on the side of the artery towards the heart in order to prevent the blood flowing through it. Arteries are apt to be deep seated and to exert pressure on an artery it is essential that the artery should be near the skin. A place where an artery runs near the skin is called a pressure point, and to apply First Aid successfully it is essential that you should know the whereabouts of these pressure points. At each pressure point a pulse may be felt. At each heart-beat blood at high pressure is pumped into the arterial system and this pressure is communicated throughout the elastic walls of the entire arterial system, causing the walls to distend. In the pause before the next heart-beat the walls recoil. The effect may be imitated by having water flowing through a rubber tube attached to a tap and then suddenly turning on the tap more forcefully. You will notice the distension of the rubber tubing; this takes place instantaneously before the water has had time to reach the distant ends of the tube. The alternate distension and recoiling of walls takes place throughout the arterial system, but it can only be felt as a pulse at places where an artery is close to the surface of the skin.

The smaller arteries (the arterioles) form a much branched system of narrow tubes in which there is considerable resistance to the blood flow. In the arterioles the swift jerky flow becomes a slower steady stream.

Increased blood flow to an organ can be caused by the dilation of its capillaries and by an increased blood pressure in the arteries supplying the organ. As a rule, increased volume of blood in one organ necessitates a decreased volume of blood somewhere else. The spleen seems to function as a reservoir of blood. It is a purplish red organ in the abdominal cavity just dorsal to the stomach. In it the blood flows from arteries to veins through large blood spaces. When the organ con-

tracts, the extra blood is squeezed out of these spaces and thus is available for other parts of the circulation. Moreover, blood-flow can be changed at the expense of the supply to other organs. Thus, after a meal, there is increased flow of blood to the alimentary canal partly at the expense of the blood in the muscles of limbs and trunk. Conversely, during exercise, there is less blood directed to the alimentary canal and more to the muscles of the trunk and limbs.

Veins.—The blood from the capillaries flows into a system of veins which gradually unite into the chief veins returning blood to the heart. The walls of the veins are thinner than those of the arteries; they have far less muscle. In the veins the blood flows evenly without jerks and at relatively low pressure. Much of the arterial pressure has been used up in overcoming the resistance of the capillaries. Attached to the inner walls of the veins is a series of pocket-like valves, one of which is shown in section in Fig. 32. If it were not for these valves there might be a tendency for the blood to flow backwards, but this is immediately prevented by the filling of the pockets with blood. When filled with blood the pockets stretch right across the vein and effectively prevent further flow. Even so there may be a certain amount of stagnation of blood in the veins when the body is quite still. When in motion the muscles squeeze on the veins and thus have the effect of pushing the blood on towards the heart.

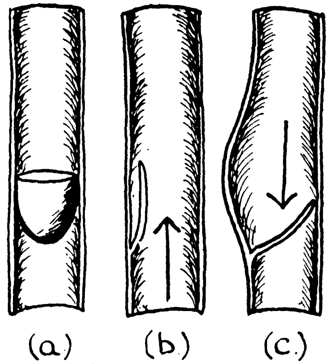


FIG. 32.—(*a*) Vein cut open to show one of the valves; (*b*) and (*c*), section through a valve to show how it acts in preventing blood from flowing the wrong way.

THE HEART

The heart is in the thorax just above the diaphragm and in the middle line.

A sheep's heart is particularly suitable for examination

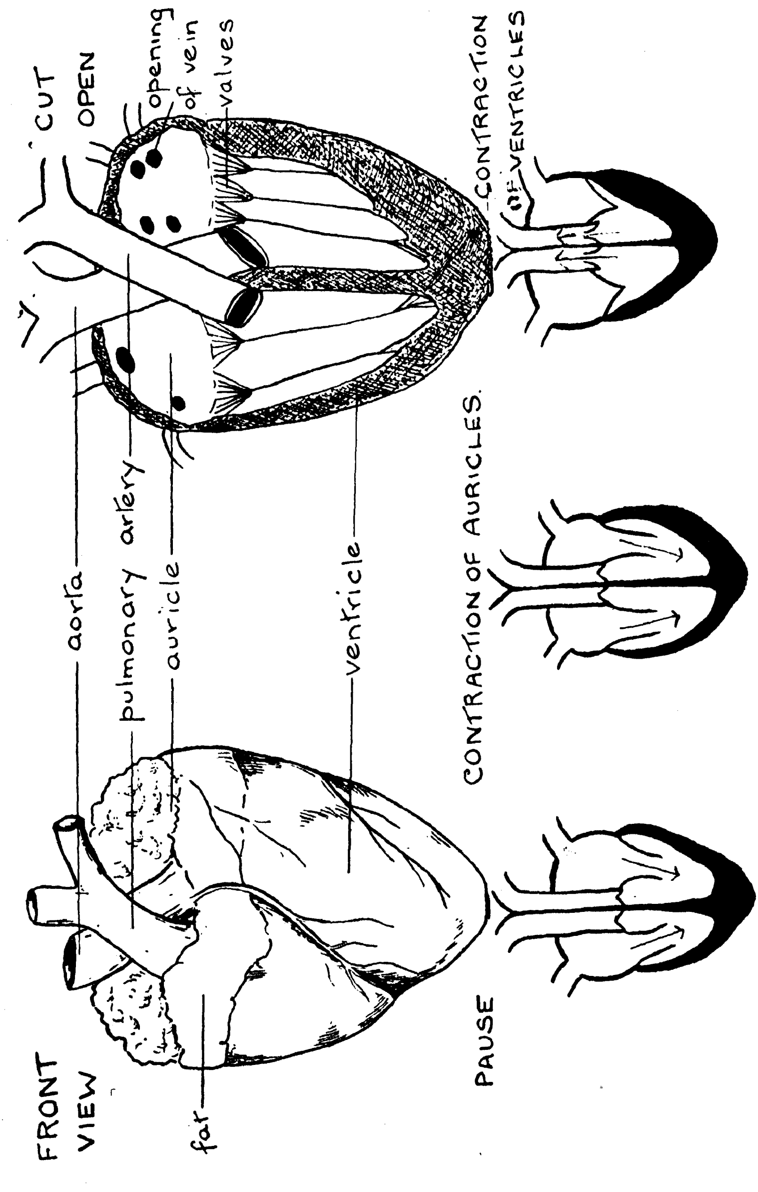


FIG. 33.—Structure of sheep's heart.

(Fig. 33); the ventral side of this is convex while the dorsal side is flat. It consists of four muscular chambers, the anterior ones being called **auricles** and the posterior ones **ventricles**; the ventricles have much thicker walls than the auricles and the left ventricle has exceptionally thick walls. The right and left sides of the heart are quite separate from one another, but on each side auricle and ventricle can communicate with one another, subject to the action of curtain-like valves between auricle and ventricle. Between right auricle and right ventricle there are three such curtain-like valves, and between left auricle and left ventricle there are two such curtain-like valves. The valves are anchored to the walls of the ventricles by white cords. When you examine the heart you will notice the cut ends of the great blood vessels. Leading from the ventral side of the ventricles are the great arteries: the **pulmonary artery** from the right ventricle taking the blood to the lungs, the **aorta** from the left ventricle taking blood to all the rest of the body. The pulmonary artery crosses over in front of the aorta very near their place of origin, but you will be able to convince yourself of the exact place of origin of each by pushing a glass rod down into each and feeling where it leads to inside the heart. In each ventricle the entrance into the artery is guarded by three pocket-like valves. The main veins of the body bring blood back into the dorsal side of the auricles; the right and left **pulmonary veins**, bringing blood back from the lungs, enter by separate openings into the left auricle, while the three **venæ cavæ**, bringing back blood from the rest of the body, enter the right auricle.

Heart muscle has the power of contracting and relaxing rhythmically 72 times a minute. Let us consider the beating of the heart starting from the pause between one beat and the next (Fig. 33). Blood is flowing steadily from the venæ cavæ and pulmonary veins into the auricles and through into the ventricles. The curtain valves are pressed against the sides of the heart and do not impede the flow. The blood accumulates in the ventricles, thus increasing the pressure, for the watch-pocket valves are touching one another, thus closing the entrance to the arteries. Next, the muscular walls of both

auricles tighten (or contract) and an extra amount of blood is forced into each ventricle, thus increasing the pressure. Almost immediately both ventricles contract very forcibly so that the pressure of blood in them is tremendous. The pressure of the blood under the curtain-like valves forces them towards one another until they touch, thus closing the entrance to the auricles. The pressure of blood would be sufficient to turn them inside out and push them right up into the auricles, but they are held in position by the white cords. At the same time the pocket-like valves in the arteries are pushed apart by the great pressure and blood escapes with great force into the pulmonary artery and the aorta. The pressure in the aorta is particularly high, for the left ventricle, with its much thicker muscular walls, is capable of more powerful contraction than the right ventricle. After this, the ventricles relax and the pressure in them falls rapidly below that in the arteries, reflux of blood being prevented by the closing of the pocket valves. All this time blood has been flowing into the auricles from the veins, the pressure in the auricles is now great enough to force open the curtain-like valves, and the cycle starts again.

When you feel your heart beating you are feeling the contraction of the left ventricle, hence you feel the beat slightly to the left of the middle line. By means of a stethoscope a doctor can hear sounds accompanying the heart-beat, the powerful contraction of the ventricles produces a prolonged sound rather like ' lu-u-u-b '. This is followed immediately by a short sharp sound rather like ' dup ', caused by the closing of the pocket valves. Then there is a silence, occupied by the relaxed stage of the heart and by the contraction of the auricles, which is inaudible. You can make an imitation stethoscope by using a thistle funnel attached to a long rubber tube, by which means you can hear the sounds made by the beating of your own heart. During vigorous exercise the heart-beat is more powerful and sometimes more rapid; emotional states also influence the beat.

THE COURSE OF THE CIRCULATION

Blood leaves the heart by arteries and returns by veins. In the previous section you will have noticed that there are two arteries from the heart: one is the aorta leading from the left ventricle and the other is the pulmonary artery leading from the right ventricle. Similarly, there are two sets of veins returning blood to the heart: venæ cavæ go into the right auricle and pulmonary veins go into the left auricle. We shall understand the significance of this if we trace the course of the blood which has just been forced out from the left ventricle via the aorta. This blood is supplied to all the tissues of the body, except the lungs, and in every organ the blood flows through capillaries. From the capillaries the blood is gathered up into veins which carry it to the main veins of the body. The veins from the alimentary canal unite into the portal vein, but this does not communicate directly with the vena cava; it passes into the liver, where it breaks up again into capillaries and finally joins the vena cava via the ordinary veins of the liver. The venæ cavæ bring the blood back to the right auricle. In its passage through the tissues the blood will have lost its oxygen and thus it is de-oxygenated blood

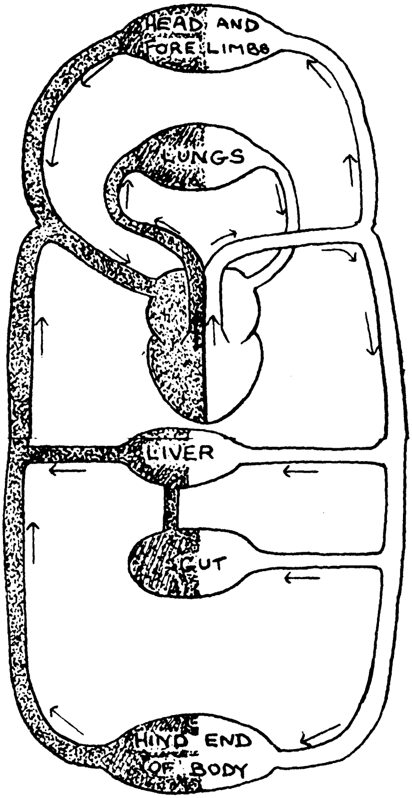


FIG. 34.—Scheme of circulation (ventral aspect.)

which flows into the right auricle. The blood is forced into the right ventricle and out through the pulmonary artery to the lungs. In the lungs the blood gains oxygen (see Chapter IX) and oxygenated blood returns to the left auricle via the pulmonary veins. Thus there is a double circulation in the body, one through the lungs only, starting at right ventricle and finishing at left auricle. This is sometimes called the pulmonary circulation. The other circulation is a much larger circuit and involves all the body except the lungs; it starts at the left ventricle and ends at the right auricle; it is sometimes called the systemic circulation. The effect of this double circulation is that the blood returning from the tissues in the systemic circuit is sent through the lungs where it is oxygenated before being sent out to the tissues again. Fig. 34 is a scheme of the double circulatory system. Remember that it is a scheme and not a picture. For convenience, arteries and veins have been widely separated: in the body both the aorta and the vena cava occupy the middle line.

QUESTIONS

1. *A mammal has a double blood circulation. With the aid of a diagram explain what this means. Trace the path of a red blood corpuscle from the lungs to the leg.*

2. *What do you know of the uses of the following: (a) Valves of the heart, (b) lymph, (c) white blood corpuscles, (d) red blood corpuscles?*

3. *Answer all the parts:*

(*a*) *What are the pressure points and why are they significant?*

(*b*) *A person who is very ill may be fed by injections into the blood. Why is it not practicable to provide him with oxygen by injecting air into his blood?*

(*c*) *What do you know of the structure and uses of capillaries?*

CHAPTER VI

SOME CHEMICAL SUBSTANCES OF PLANT AND ANIMAL BODIES

As you would expect, the chemistry of a living organism is complex. Chemists are able to analyse the materials of plant and animal bodies, and, although they detect the presence of a good many elements, they find that carbon, hydrogen, oxygen and nitrogen are the dominant ones. Nearly all plant and animal compounds contain carbon, hydrogen and oxygen, and a good many compounds contain nitrogen also. Now, compounds containing carbon are apt to be very varied and very complex, for there is an enormous number of possibilities of chemical combination. Carbon compounds are called organic compounds, and you will find out further details about their construction in the *Chemistry* book in this series.[1]

Plants and animals have the power of building up many and varied organic substances.[2] Some of these form the actual structure and framework of the body, and may be called **structural materials** ; others act as food reserves which may be mobilized for use at any time, and they may be called **storage materials** ; while chemical substances conducted about the body of a plant or an animal form yet a third category, **transport materials.** Many plant and animal substances, whether structural, storage or transport materials, belong to one or other of three important classes of compounds, viz., carbohydrates, fats and proteins.

CARBOHYDRATES

The carbohydrates are compounds containing carbon, hydrogen and oxygen only, and there is twice as much hydrogen present as compared with oxygen.

[1] *Chemistry*, A. W. Wellings, uniform with this volume.

[2] The many and varied chemical changes taking place in an animal or plant (both building up and breaking down) are classed under the general term **metabolism.**

Sugars are soluble carbohydrates, and the simplest common sugar is glucose, which is one of the so-called hexose sugars with formula $C_6H_{12}O_6$. It is of very widespread occurrence in all plant and animal tissues and seems to be an important transport material. It will easily absorb another atom of oxygen and become converted into an acid. Hence glucose acts as a reducing agent (see *Chemistry* book [1]), and its reducing action may be used to detect it.

Test for Glucose.—Dissolve a small quantity of glucose in water in a test tube. Add an equal quantity of Fehling's solution A (consisting of sodium hydroxide and sodium potassium tatrate) and a very small quantity of Fehling's solution B (consisting of copper sulphate). Boil the mixture and you will see that a precipitate forms; this is at first green and then orange red. Fehling's solution consists of a complex copper compound and may be regarded as cupric oxide in solution. When this is reduced by the glucose it forms the orange red cuprous oxide. Fehling's test may be used to detect the presence of a reducing sugar in a food. Golden syrup, honey, barley sugar, fruit juices, all contain glucose which may be detected by Fehling's test.

More complicated sugars, such as maltose, sucrose and lactose, have the formula $C_{12}H_{22}O_{11}$. Sucrose is the ordinary sugar you buy at the grocer's; it is present as a transport material in all plants, but it is particularly abundant in the sugar-cane and in the sugar-beet, where it forms a storage material as well. It is not worth cultivating a plant for its sucrose content unless it contains sucrose as a storage material. Maltose is present during the germination of starch containing seeds (see Chapter VII, page 85), while lactose is the sugar in milk. Both maltose and lactose act as reducing sugars and hence respond positively to Fehling's test. Sucrose, however, is not a reducing agent. Now sucrose can be split up into simpler hexose sugars if it is boiled with a few drops of acid. The hexoses formed in this reaction will, of course, respond positively to Fehling's test and this gives us a way of detecting sucrose.

Test for Sucrose.—Make a solution of sucrose in water and divide it into half. To one half add Fehling's solution and heat. There is no

[1] *Chemistry*, A. W. Wellings, uniform with this volume.

change, since sucrose is not a reducing sugar. To the other half add a few drops of concentrated hydrochloric acid and boil for about two minutes. Then heat with Fehling's solution, and be careful to add plenty of solution B so that the acid is neutralized by the sodium hydroxide. On continued heating, an orange-red precipitate forms. The test for sucrose may also be applied to foods which contain it, such as biscuits, jam and cakes.

The most complex carbohydrates are insoluble substances having a formula, $(C_6H_{10}O_5)_x$, where x is at least 2,000. **Starch** is the commonest complex carbohydrate; it is found as a storage material in the majority of plants. If you cut a very thin piece of potato tuber and examine it under the microscope you will see that the cells are laden with oval starch grains (Fig. 35). Starch forms a bluish-black compound with iodine, and this is a useful test for the presence of starch in foods. No starch is found in animal bodies; here its place is taken by a similar complex carbohydrate called **glycogen**; this reacts with iodine to give a port-wine colour. Cellulose is a structural carbohydrate present in the cell walls of plants. This does not react with iodine at all until it has been treated with concentrated sulphuric acid and then a blue colour is produced.

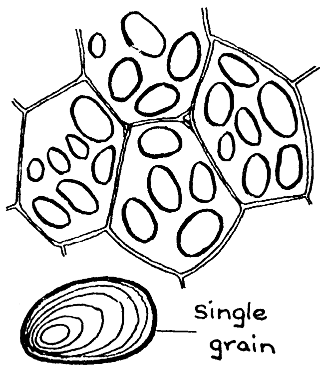


FIG. 35.—Starch grains in cells of potato tuber.

FATS

Fats are important storage materials in both animals and plants. Plant fats are usually liquid and may be called oils; they are particularly abundant as stores in many seeds. Animal fats (e.g. suet) are often of a firmer consistency; they are found just under the skin and also in the connective tissue between the internal organs. The connective tissue in the neighbourhood of the kidneys is often laden with fat. Milk and eggs contain fat in a liquid state.

Fats contain the same elements as carbohydrates, but the proportion of oxygen is very much less. Actually fats are compounds of various complicated acids with the alcohol glycerol. (For further details see *Chemistry* book.[1])

Test for Fats.—Fats can be detected by their greasy nature, and if the plant or animal material is rich in fats, brisk rubbing on a piece of paper leaves a translucent mark. Thus Brazil-nuts or pea-nuts will leave such a grease mark. If fats are present in smaller quantities the material is pounded up with ether and the liquid is poured on to a piece of paper. Ether extracts the fat from the material, and as it evaporates, the greasy mark, due to the fat, is clearly seen. If you use ether, remember that it is a highly inflammable liquid.

PROTEINS

The most complicated of all plant and animal materials are the proteins. These are important structural materials, for they are major constituents of protoplasm itself. Hence, all living tissues contain proteins; in the animal body muscle tissue is particularly rich in proteins, and in the last chapter we mentioned the proteins of blood plasma. Sometimes proteins are formed as storage materials; this is the case in certain seeds such as peas and beans and in the yolk and white of eggs and in milk. Proteins may split up into simpler substances called **amino acids.** There are about 22 of these amino acids and they may be regarded as the varieties of units from which proteins are built. All 22 varieties are not represented in any one protein. Imagine being able to build with 22 different kinds of bricks with no limit on the number of each which you can use! What a great variety of structures you could produce. This will give you some idea of the variety and complexity of the proteins. Even one of the simpler proteins called edestin has the formula $C_{622}H_{1020}H_{193}O_{201}S_4$.

Tests for Proteins.—The tests for proteins depend on their construction from amino acids. They can be tried with white of egg (or dried egg in water) or milk.

The Biuret Test.—Add an excess of sodium hydroxide and then a drop of copper sulphate. These two chemicals form a blue precipitate

[1] *Chemistry*, A. W. Wellings, uniform with this volume.

but, in the presence of a protein, a mauve solution is also produced. The formation of this depends on the nature of the linkage between the amino acids ; it is a test which is given by all proteins.

Millon's Test.—Add a few drops of Millon's reagent to the protein in water and heat. There is a rose-red precipitate, the formation of this depends on the presence of one particular amino acid called tyrosine. Such proteins as do not contain tyrosine will not react positively to this test. Actually, the majority of the common proteins do contain tyrosine, but it is not safe to assume that a particular food is quite deficient in protein simply because it does not react to Millon's test.

Xanthoproteic Test.—Add nitric acid to protein and water, and heat ; a yellow precipitate is formed. Now cool under the tap and add a few drops of ammonium hydroxide ; the precipitate turns orange. This test depends on the presence of an amino acid called tryptophane.

QUESTIONS

1. *How would you test for the chief food reserves in* (*a*) *peas,* (*b*) *cheese,* (*c*) *bread? What results would you expect?*

2. (*a*) *If you were given a white powder which might be starch, glucose or sucrose, how would you find out which it was?*

(*b*) *Name three organs in plants which store starch. Why is starch a very suitable substance for storage? Name two substances stored in a mammal, and for each mention the place where it is stored.*

CHAPTER VII

PLANT NUTRITION

Feeding is one of the major activities of living things. The life of a lion is largely occupied in hunting its food, and plant-eating animals, such as the rabbit, spend a good deal of time in feeding. The feeding of plants goes on continuously, but the process is less obvious, because they are able to use materials from the soil and air surrounding them. We must also remember that a substantially large proportion of the activities of mankind is concerned with this business of feeding. The growing of crops for food on a world scale and the rearing of domestic animals involves the labour of millions, and much of the shipping and road and rail transport is involved in food distribution. Many factories produce eatables, others produce agricultural machinery, while there are numerous shops which sell food of one kind or another.

Why is food of such immense importance? A very important use of food is to build the bodies of plants and animals. All the complicated materials of the blood, muscle and even of the brain itself are made from food, and so also are the structural materials of stem, root and leaf. Another essential use of food is to provide a fuel from which plants and animals are supplied with energy (Chapter IX). Food is also used to form reserve materials which may be stored for future use.

Let us think a little more carefully about the nature of the food required by animals and plants. Animals may feed entirely on plants (vegetarians), or entirely on other animals (carnivores), or on a mixture of plant and animal food (mixed feeders). Now carnivorous animals are really dependent on plants for their food, albeit in an indirect fashion. A lion feeds on zebras, and these animals are vegetarians and feed on grass. When we eat beef or mutton we are indirectly dependent on plants, for both oxen and sheep feed on grass. Without plants animals could not feed themselves, and hence the

nutrition of plants is of paramount importance not only to the plants themselves but to the whole of the animal world.

PHOTOSYNTHESIS

In Experiment 3 you found that a Tradescantia cutting made vigorous growth although it had access only to the air and to a soil solution of various mineral salts. Evidently, plants are capable of building up organic substances from the simple substances around them. Among the organic materials in a plant are the carbohydrates ; these contain the elements carbon, hydrogen and oxygen, and to make them no mineral matter is required. Nearly all plants contain both sugar and starch, and it seems probable that, as sugar is the simpler substance, this is made first and starch is formed afterwards. The manufacture of carbohydrates in a plant is called **carbon assimilation** or **photosynthesis.** Strictly speaking, photosynthesis consists in the making of sugar, which may afterwards be turned into starch. Actually, when we are finding out whether photosynthesis is taking place in a plant we usually apply the test for starch, but we must always remember that if starch is present sugar must have been made first.

Conditions for photosynthesis.—The non-green parts of plants, such as seeds, potatoes, bulbs, corms, can be tested for starch by direct application of iodine on a cut surface, but the green parts require special preliminary treatment to get rid of the chlorophyll, which would obscure the result.

Experiment 15.—Suitable leaves to use for this experiment are nasturtium, lupin, sycamore, hop, broad bean. Boil some methylated spirit by putting it into a beaker surrounded by a water bath. (Methylated spirit must not be heated directly because it is very inflammable.) Dip the leaf in boiling water to kill it and soften it, and then immerse it in the beaker of boiling methylated spirit until the chlorophyll is all dissolved out, leaving the leaf white or yellow. In this state, the leaf is very brittle and it must be softened by putting it in a saucer of water. Then immerse it in a saucer containing iodine, which has been diluted until it is a pale brown. After a minute or two, put the leaf back into the saucer of water to rinse off the excess iodine, and you will see that the leaf has stained a blue or blackish-blue colour.

It is quite usual for all parts of a plant to contain both sugar

and starch, but this does not necessarily mean that all parts of a plant are capable of photosynthesis. Sugar is a transport material and it can be conveyed all over the plant from the place of manufacture. Leaves are the chief photosynthetic organs, and this is partly because they are green, for chlorophyll plays an essential part in the process. Leaves which are not green cannot carry on photosynthesis, and you can convince yourself of the truth of this statement by making an experiment with a variegated leaf.

Experiment 16.—Leaves of the variegated maple, or variegated Arabis, or golden elder, are particularly suitable for this experiment. Pick a leaf on a sunny afternoon and make a drawing showing the exact positions of the green and white areas. Then decolourize it and test with iodine (for details, see Experiment 15). You will find that starch is confined to the areas which were originally green ; there is no starch present in the white areas.

If you take the trouble to test green leaves for starch at various times of the day, you will often find that leaves picked early in the morning are deficient in starch (leaves picked at dawn may not have any starch at all), whereas leaves of the same plant picked later in the day contain abundant starch. It seems that the carbohydrates of the plant are depleted during the night and built up during the day. Light is essential for photosynthesis to take place, and you can prevent photosynthesis even in the daytime if you cover up a leaf.

Experiment 17.—Suitable leaves to use for this experiment are those mentioned in Experiment 15, but let them remain attached to the plant. Cover parts of the leaves with tin-foil, securely fastened to the upper and lower surface by means of slip-on paper clips. If you like, you can cover other leaves entirely, and cut a stencil out of the middle in the shape of a triangle. Do not forget to make the stencil on the lower surface match that on the upper surface. Leave the covers in position for not less than 24 hours and not more than 48 hours. On removing the covers, notice that the leaf looks perfectly normal. (If you leave the covers on for several days, the covered parts may have started to lose their chlorophyll, and then the experiment is useless.) Decolorize the leaf in the usual way, and test for starch. You will find that starch is only present in the areas which were exposed to light.

Now we must enquire what substances are used by plants

to make sugar, for neither light nor chlorophyll provides materials for the process. We have said that the elements of sugar are carbon, hydrogen and oxygen, and these are readily obtained from the carbon dioxide of the air and the water of the soil. The supply of water is abundant, but you will know that the amount of carbon dioxide in the air is very little (only 3 parts in 10,000). Nevertheless, the carbon dioxide of the air is the sole source of the carbon of carbohydrates, and, if the air is deprived of carbon dioxide, no photosynthesis takes place.

Experiment 18.—This experiment is best carried out with a large compound leaf belonging to the pea and bean family. (Galega is

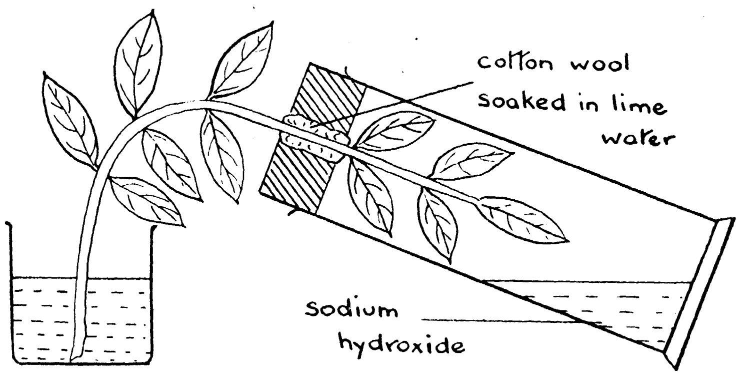


Fig. 36.

particularly suitable.) At the outset of the experiment the leaf should be free of starch, and this is best assured by covering the leaf, while it is still on the plant, with a black paper bag for 48 hours. During this time the carbohydrates of the leaf are depleted and the leaf is starch free. Now cut off the leaf from the plant, remove the bag and arrange it as shown in Fig. 36. The sloping gas-jar can be kept in position by leaning it against the clamps of a retort stand or by using wooden blocks. The sodium hydroxide solution in the gas-jar absorbs carbon dioxide, and you must be careful to ensure that the solution does not touch the leaflets. The top of the gas-jar is closed by two halves of a split cork placed together round the leaf stalk. A thin covering of cotton-wool round the leaf stalk at this place ensures that it is not damaged. You must soak this cotton-wool in lime-water to absorb any carbon dioxide that might enter. The two halves of the cork are

thoroughly waxed to make them air tight and the whole apparatus is left in a good light for two days. Then decolorize and test for starch in the usual way, and you will find that only the leaflets outside the jar, which had access to ordinary air, turn blue with iodine. The leaflets inside the jar in the air without carbon dioxide have no starch.

It is possible to do this experiment with leaves such as hop, nasturtium, runner bean, but with these it is necessary to have all the blade of the leaf inside the gas-jar and to use another complete leaf as a control.

Photosynthesis in the Leaf.—Let us consider the actual process of photosynthesis a little more closely. Carbon dioxide and water combine to form sugar. The reaction is a process of reduction involving the liberation of oxygen and, like all chemical reductions, it requires energy to bring it about ; this energy is supplied by light. We have seen that chlorophyll is also essential, and it seems that its function is to absorb the light energy and so make it readily available for the reduction process. Photosynthesis may thus be summarized :

$$\begin{tikzcd} 6H_2O + 6CO_2 \arrow[r, "\text{light energy}", "\text{absorbed by chlorophyll}"'] & C_6H_{12}O_6 + 6O_2 \arrow[d, shift right] \\ & \text{Starch.} \arrow[u, shift right] \end{tikzcd}$$

Actually, this scheme represents only the beginning and end of a series of reactions, for various intermediate substances are formed. In the series of reactions chlorophyll seems to play the part of a catalyst.

Leaves are the photosynthetic organs of the plant and your knowledge of the structure of a leaf will convince you that it is particularly well suited to this work. To begin with, leaves expose a large area to sunlight. Stand under a horse chestnut or a lime on a summer's day and look up at the leaf canopy, then you will get some idea of how vast this surface area is ; it is only here and there that you will see tiny chinks of blue sky between the leaves. This vast area enables the leaves to make the best possible use of the small quantity of carbon dioxide present in the air. This carbon dioxide diffuses

through the stomata into the internal atmosphere of the leaf, from which it is absorbed by the chloroplasts of the mesophyll cells. It is in the chloroplasts that the actual reaction takes place. If you look again at the internal structure of a leaf (see Fig. 11) you will realize that the mesophyll cells are in contact with quite an extensive internal atmosphere and, since every mesophyll cell contains many chloroplasts, the total surface area through which carbon dioxide is absorbed is enormous. Water is supplied to the mesophyll cells via the network of veins, and we have already considered the mechanism of water transport in Chapter IV.

Oxygen production in photosynthesis.—In the last section it was stated that photosynthesis is a process of reduction involving the liberation of oxygen. We can show that a green plant gives off oxygen in the light by the following experiment :

Experiment 19.—Set up some green shoots tied to a glass rod under a bell-jar as shown in the diagram in Fig. 37 (mint shoots are quite suitable), and, at the same time, arrange another piece of apparatus to act as a control, omitting the shoots. Suspend a lighted candle on a wire into each bell-jar, and then put plasticine round the stoppers to make them air-tight. The candles burn in both bell-jars until the oxygen supply is deficient, then they go out. Now leave both pieces of apparatus in good light for about three days. After this, test the air in each bell-jar with another lighted candle. You will find that in the bell-jar containing the shoots the candle will continue to burn, hence some oxygen must have been produced. In the control experiment the candle goes out at once.

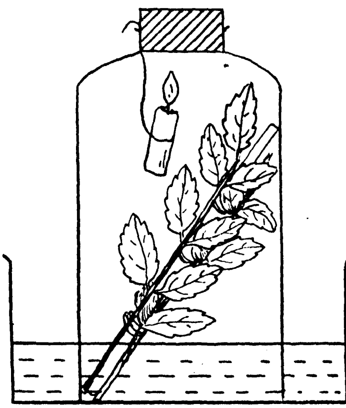


FIG. 37.

By using a water plant it is possible to collect impure oxygen from a plant.

Experiment 20.—Fill a flask with water through which carbon dioxide has been bubbled, insert some healthy shoots of a water plant (Elodea

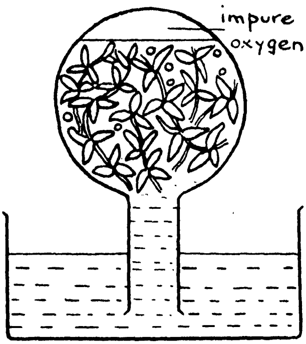


FIG. 38.

is particularly suitable). Then invert the flask in a dish of water and support it by clamps. If you put the apparatus in a good light you will notice bubbles rising from the shoots and collecting in the flask. After a few days there is a reasonable amount of gas in the flask (Fig. 38). Put a stopper in the neck of the flask and remove it on to the bench the right way up, so that the gas is now in the neck of the flask. Remove the stopper and thrust in a glowing splint; this immediately bursts into flame.

The production of oxygen by green plants in the light has been known for a very long time, for Experiment 19 was first carried out in the eighteenth century by Priestley, the discoverer of oxygen; only at a much later date was this production of oxygen associated with food manufacture by plants. It is obvious that the evolution of oxygen in photosynthesis is of great significance. The oxygen of the air is constantly being removed by burning of fires, by breathing and by decaying processes; and if it were not for plants the oxygen would gradually be used up entirely. Photosynthesis restores oxygen to the air so that the proportion is fairly constant at 21 per cent.

THE USING OF SUGAR BY PLANTS

Most of the sugar made in the leaves is transported in the vascular bundles to other parts of the plant where it is used to make all the structural and storage materials, and is also used as a fuel. Carbohydrate structural materials, such as cellulose walls, and carbohydrate food reserves, such as starch, can be formed from sugar alone. Fats can also be formed from sugar alone. However, proteins, whether the structural proteins of protoplasm or the storage proteins found in some seeds, cannot be made from sugar alone, for they contain nitrogen as well as carbon, hydrogen and oxygen. The nitrogen is obtained from nitrates and ammonium salts in the soil.

All our crops depend for their formation on the sugar drift from the leaves. Thus, in a potato plant part of the sugar is used for the development of new aerial shoots and new rhizomes, and part of it is deposited as starch in the swelling tubers. Wheat grains are developed and loaded with starch by the sugar supply from the leaves. Sometimes sugar is stored as such without changing into starch; such is the case in carrots, beetroot, plums, apples and other fruits. Farmers and gardeners know that good crops depend on healthy vigorous leaves, and before stripping a plant of its foliage you must always remember the effect of this on the rest of the plant. Some over zealous amateur gardeners are so anxious to keep their daffodil and tulip beds tidy that they cut off the shoots as soon as flowering is over; of course this is disastrous, since without leaves no food can be made for the new bulbs.

Photosynthesis is an active process, and during the hours of daylight more sugar is made in the leaf than is transported away to the rest of the plant. Part of this sugar is used as a fuel by the leaf itself, and much of the rest of it is turned to starch, which accumulates in the leaf. During the night photosynthesis ceases, and so the losses of sugar from the leaf to the rest of the plant are not made good, and the starch of the leaf is gradually turned back to sugar.

THE RÔLE OF MINERAL SALTS

In Experiment 3 we found that the soil mineral salt solution is essential for plant growth. The plant in distilled water did not grow although it had all the conditions necessary for photosynthesis. There are many elements in the soil mineral salt solution and it is important that we should find out which of them are required by plants.

To do this it is necessary to prepare a set of solutions each of which lacks one of the elements in the soil solution. If cuttings are grown in these solutions and their growth compared with that in the full solution, it is easy to separate the essential from the non-essential elements. From such experiments it is found that the following elements must be present for healthy plant growth: nitrogen, sulphur, phosphorus, potassium,

calcium, iron and magnesium. A solution containing potassium nitrate, magnesium sulphate, calcium sulphate and iron phosphate is almost as good for the growth of plants as the natural soil solution.

Experiment 21.—You can try the effect of leaving out a few of the essential elements by comparing the growth of plants with the growth made in the full solution. This is called a water culture experiment. Recipes for the full solution and two others are given below:

Ingredients.	Full Solution.	Lacking Nitrogen.	Lacking Iron.
Distilled water . .	2,000 c.c.	2,000 c.c.	2,000 c.c.
Potassium nitrate . .	2 gm.		2 gm.
Potassium chloride . .		2 gm.	
Iron phosphate . . .	0·5 gm.	0·5 gm.	
Calcium phosphate . .			0·5 gm.
Calcium sulphate . .	0·5 gm.	0·5 gm.	0·5 gm.
Magnesium sulphate .	0·5 gm.	0·5 gm.	0·5 gm.

Notice that you cannot leave out a certain element simply by omitting the compound which contains it. For instance, if you omit potassium nitrate you are leaving out potassium as well as nitrogen; therefore, to make a solution lacking nitrogen but containing potassium you must replace potassium nitrate by potassium chloride.

In making up the solutions be sure to use absolutely pure water and make certain that the bottles in which you store the solutions are perfectly clean. To grow the cuttings, use apparatus and method similar to that described in Experiment 3. If available, it is desirable to use large gas-jars (capacity at least 2 quarts) instead of 2-lb. jam-jars. Set up cuttings in the following liquids: full solution, solution lacking nitrates, solution lacking phosphates, solution lacking iron, distilled water.

As the cuttings develop you will notice marked differences. The

plant in distilled water has scarcely developed at all, that in the solution lacking nitrates is often almost as bad. In the solution lacking iron considerable growth has taken place, but the leaves are yellowish instead of green.

In recent years the results of water culture experiments have been applied commercially. It has been found possible to grow crop plants successfully with their roots in a suitable full solution of mineral salts provided that there are adequate means of aerating the solution. Some people without gardens have grown plants very successfully in tanks of solution on flat roofs or balconies.

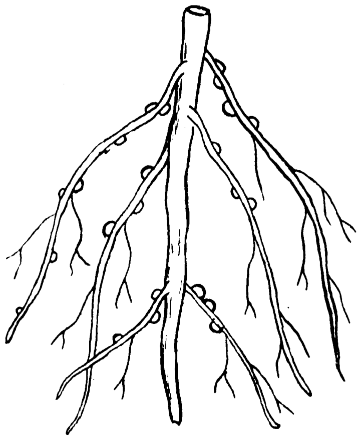


FIG. 39.—Part of root system of Galega, showing nodules.

Nitrogen is probably the most essential element in the mineral salt solution, for it is used, together with sugar, to make plant proteins, and the supply of soil nitrates or of ammonium salts to crops is one of the most important agricultural problems. From man's point of view it seems a pity that plants are unable to use the vast supplies of the element nitrogen in the atmosphere. Only one class of plants is able to do this, viz., plants of the pea and bean family. These plants have swellings on their roots called nodules (Fig. 39), and these contain many thousands of a certain bacterium which lives in partnership with the plant. The plant manufactures sugar in the ordinary way by photosynthesis, and with the help of this sugar the bacterium is able to make proteins, using the nitrogen from the soil atmosphere. These proteins are not only used by the bacterium but by the plant as well. Peas, beans and related plants are independent of soil nitrates, and if you had used a bean plant in Experiment 21 the plant in the solution without nitrates would have been as vigorous as the plant in the full solution.

Except for nitrogen, the rôle of the various mineral elements is rather obscure. It is probable that sulphur and phosphorus are needed to make some of the protoplasmic proteins. Other elements may act by influencing the physical properties of the protoplasm. Thus, potassium and calcium seem to affect the permeability of the protoplasm. Iron and magnesium both affect the chlorophyll content ; magnesium enters into the composition of chlorophyll, while iron is necessary for its formation.

It seems probable that no one salt acts on the plant in isolation ; healthy growth and development depend very largely on a balanced supply of mineral salts, and wise gardeners bear this in mind when they manure the soil. If you carry out a water culture experiment, using one cutting in distilled water and one in a solution of a single essential salt, then the growth of the cutting in the latter may be even worse than in distilled water. In manuring the soil it is often unwise to add a single salt which may upset the salt balance of the soil. That is why amateur gardeners are advised to use a 'General Purposes Fertilizer' containing a mixture of salts.

The mineral salt solution in the soil is a very dilute one and the dissolved substances pass into the root hairs with the water, provided the protoplasm is permeable to them. You will realize that the continual passage of water through a plant in the transpiration stream enables a maximum quantity of mineral salts to enter the plant.

DECAY UNDER NATURAL CONDITIONS

We have seen that plants remove various mineral salts from the soil and combine them into the substances of their bodies. Subsequently, these substances may pass into the bodies of animals which eat the plants. Hence the soil is continually depleted of mineral salts, and it would seem obvious that growth of vegetation could only continue for a limited period until all the mineral salts had been used up. Yet the vegetation of a meadow or a wood continues to flourish year after year, and it continues to support various insects, birds and mammals, either directly or indirectly. This is because

dead parts of animals and plants decay in the soil. In the process of decay their complex substances are broken down and finally the simple mineral salts are restored to the soil to be used by the current generation of plants.

The agents of decay are the living organisms of the soil (see Experiment 5 in Chapter III). These break down the complicated plant and animal residues into simpler ones which they can use for food. These residues contain carbon, hydrogen and oxygen, and some contain nitrogen as well. Compounds in animal droppings containing the same elements are also decayed in the soil. In the decaying, some of the carbon is set free to the air as carbon dioxide, some of the hydrogen forms water and some of the nitrogen is combined with hydrogen to form ammonia. You can sometimes detect the smell of ammonia from a manure heap as it decays. Much of the residue is left in a semi-decayed state as humus.

The ammonia is not permanent in the soil, for there are certain types of bacteria, known as **nitrifying bacteria**, which are able to oxidize it. One set of bacteria oxidize it to nitrous acid, which immediately combines with carbonates in the soil to form nitrites. Another set of bacteria oxidizes the nitrites to nitrates. Thus, although soil nitrates are continually removed from the soil to form plant and animal bodies, the nitrogenous part of these is ultimately returned to the soil as nitrates. The cycle of changes undergone by the nitrates is called the nitrogen cycle in nature and this is shown in Fig. 40. In this scheme the part played by plants of the pea and bean family is also shown. These plants are independent of soil nitrates because they make their proteins from the nitrogen of the air with the help of the bacteria in the root nodules; when the plants decay the nitrates which are formed represent an addition to the soil supply.

The cycle of changes undergone by other elements in the mineral salts of the soil is not known.

MANURING

In the natural state the soil is eternally fertile, but this is very far from being the case in soil which is cultivated.

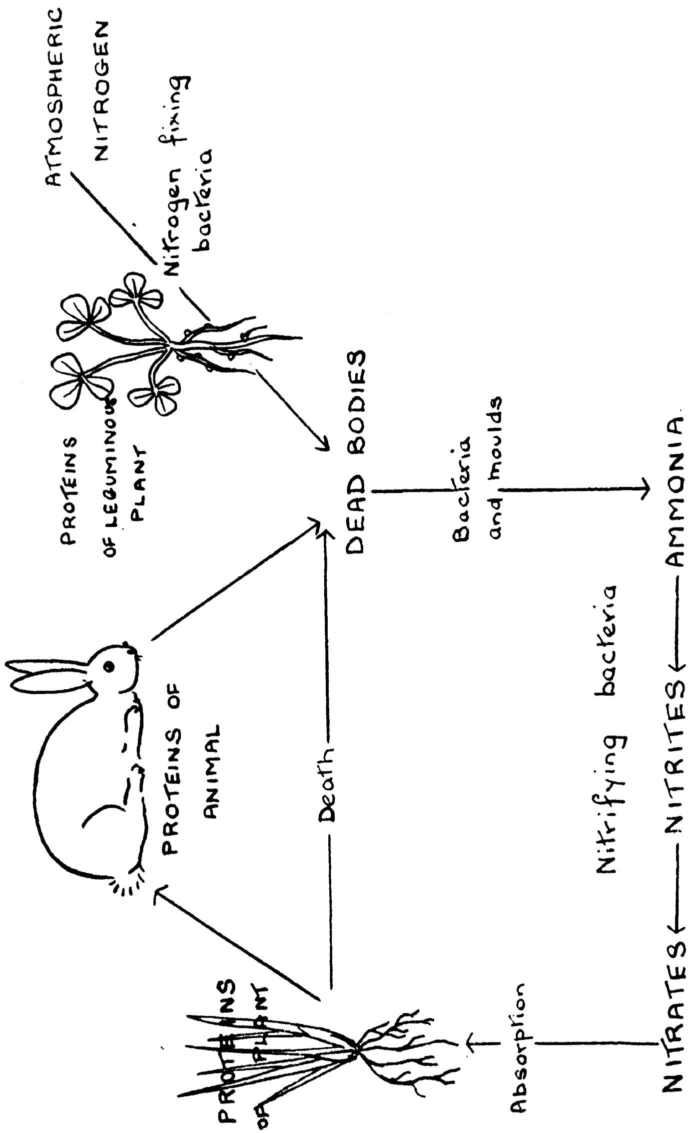


FIG. 40.—Scheme of the nitrogen cycle in nature.

Consider the growth of wheat or potatoes. The mineral salts of the soil are removed to build up the plant body; then, at the end of the growing season, when the farmer harvests his crop, he removes it from the soil, so that the substances removed from the soil are not restored to it by decay of the plants. If the soil is continually cultivated its mineral salts will be completely exhausted; moreover, its humus content will not be replenished, and in time such a soil is completely useless for the growth of any vegetation.

To keep cultivated soil in a fertile condition it is necessary to manure it. Farmyard manure is a so-called natural manure; it consists of animal droppings mixed with straw, and in the gradual process of decay mineral salts are added to the soil, together with humus. Farmyard manure is slow acting, and the proper time for applying it is in the autumn at the time of digging and ploughing, so that it may have time to start decaying before the planting of the next crop. In these days, farmyard manure is scarce, and in gardens and allotments other natural manures, such as compost and hop manure, have to be used. You will realize that a manure must not be too costly or there will be little profit to be made from the growing of crops.

Soils are also manured with such substances as ammonium sulphate, calcium nitrate, 'superphosphate' (a soluble compound of calcium phosphate and sulphuric acid), 'basic slag' (a compound of calcium phosphate and lime). All of these are chemical compounds which can be directly absorbed by the plants, and these so-called artificial manures act quickly, since there is no need for them to decay. You will perhaps wonder why farmers and gardeners bother to use the slow acting natural manures at all. The use of artificial manures has two disadvantages. In the first place, they are liable to upset the salt balance in the soil unless a careful mixture is made, and, in the second place, they do not yield any humus for the soil. As we saw in Chapter III, humus has many useful physical qualities, which render it a very desirable constituent of a fertile soil. Wise farmers and gardeners make use of both natural and artificial manures. They use the

latter particularly in the active season to stimulate growth. Artificial manures must not be too costly, and the most economical ones are those which are produced as bye-products in chemical works. For instance, ammonium sulphate is a by-product in the manufacture of coal gas, while basic slag is a by-product of steel works.

From an economic point of view, the nitrogenous manures, both natural and artificial, are the most significant. Plants use up the nitrates of the soil more than any other mineral constituent, and, without a continuous supply of nitrates, plant growth becomes impossible. In the early years of this century considerable anxiety was felt about the supplies of nitrogenous manures. The chief artificial manure containing nitrogen was sodium nitrate from Chile, and it was obvious that the deposits in Chile were by no means inexhaustible. The supply of ammonium sulphate was not sufficient to meet the world demand and neither was natural manure sufficiently plentiful. When the Chile deposits were exhausted the world would have been threatened with starvation, and it seemed a fantastic situation that this should be due to lack of nitrogen when four-fifths of the air around us contains the very element required. Chemists set themselves the task of converting the nitrogen of the air into compounds which plants can absorb, and you can read the story of this fixation of atmospheric nitrogen in the *Chemistry* book.[1] In all industrial countries nitrogen of the air can be converted into nitric acid and nitrates.

ENZYMES

In this chapter we have been considering some of the chemical changes which go on in plants, and we have seen that the structural and storage materials can all be made with the help of the all-important sugar made in photosynthesis. The storage materials are, of course, not permanent, for sooner or later they are used up to promote growth. When a potato tuber grows, its store of starch is used up ; similarly when a bean seed germinates, its reserves of starch and protein dis-

[1] *Chemistry*, A. W. Wellings, uniform with this volume.

appear. Starch is not used as such, it is converted first into sugar, which is a soluble transport material, and similarly storage proteins are converted into soluble forms before being used.

Plants contain special catalysts which enable these reactions to take place. From your work in chemistry you will be familiar with a catalyst as a substance which speeds up the rate of a chemical action but is unchanged at the end of the reaction. Finely divided platinum is a very useful catalyst for bringing about many important chemical actions, including the industrial manufacture of sulphuric acid. The catalysts in living organisms are much more specialised than this, for the catalyst which enables starch to be hydrolysed into sugar has no effect on proteins. A catalyst in a living organism is usually called an **enzyme** and plants contain many different kinds. In the next chapter we shall have more to say about enzymes in connection with the part which they play in the digestion of food. Meanwhile, you can do quite a simple experiment to demonstrate the existence of a plant enzyme which acts as starch. This enzyme is called diastase.

Experiment 22.—Scatter a large handful of barley grains or wheat grains into a bowl containing wet cotton wool covered by filter paper. Cover the bowl and allow germination to take place until the shoots are at least ¼ inch long. During this time the starch in the grains will have been converted into sugar by the agency of the enzyme diastase. Now remove the seedlings into a mortar containing some clean white sand and water and grind the mixture together. The sharp sand particles rupture the cereal grains, thus liberating the diastase which dissolves in the water. Filter the solution and add the filtrate to a tube containing 2 per cent. starch paste. Leave the tube in a warm place for at least a day together with a control tube containing starch only. Then test for the presence of sugar with Fehling's solution. The tube containing the plant extract has some sugar formed from the starch by diastase; the control tube has none.

The sugar formed from starch with the help of diastase is malt sugar (maltose). The malt used in beer making is made from barley by allowing the grains to start germinating so that the diastase turns the starch into maltose. Then, before

the maltose is used up in growth, the mass of seedlings is killed by heating it.

IRREGULAR NUTRITION IN FLOWERING PLANTS

Photosynthesis in plants depend on chlorophyll. A few kinds of flowering plants have no chlorophyll, and so they are unable to make their own sugar and have to live on organic matter. Such a plant is dodder (Fig. 41), which grows on

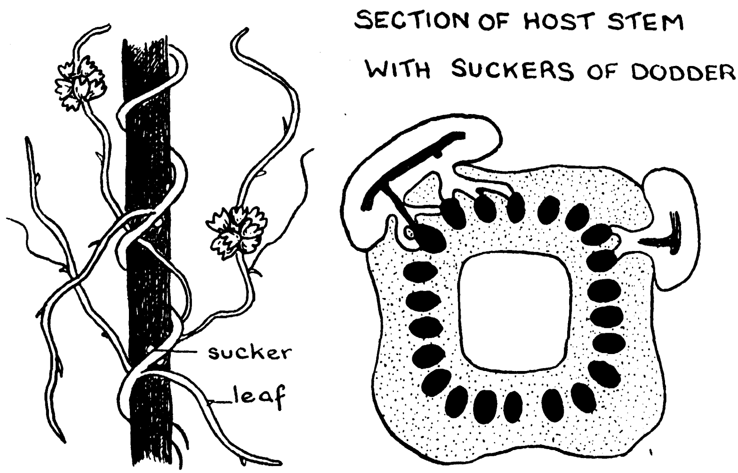


FIG. 41.—Dodder.

clover, gorse, heather and other plants, and obtains its food from these plants. An organism which lives at the expense of another is said to be a **parasite**, and the organism which is attacked is called the host. Dodder has a twining stem, and from this there grow out suckers which penetrate the stem o the host, and come into close contact with the vascular bundles. The suckers absorb water and organic food from the host. You will notice that the leaves of dodder are very minute It has a very large number of flowers from which numerou seeds are produced. Very many of the seeds are wasted, for only the young plants which come in contact with a suitable host can survive.

Some flowering plants which are somewhat deficient in chlorophyll live as partial parasites on their hosts. Such a plant is mistletoe which grows on various trees, such as apple and poplar.

Certain very peculiar flowering plants can carry out photosynthesis in the usual way but have an extraordinary method of obtaining their proteins. The sundew (Fig. 42) is common in the boggy parts of moors; its leaves are covered with sticky red hairs; some of these are sensitive to contact and close round the body of any small insect which alights on the leaf. Then various enzymes which attack proteins are secreted and the protein parts of the fly's body are digested and absorbed into the leaf. Sundew is said to be an insectivorous plant. Boggy areas are apt to be deficient in soil nitrates because decay is impeded by inadequate oxygen supply. However, insectivorous plants are independent of soil nitrates.

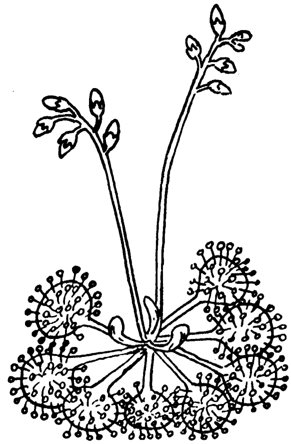


FIG. 42.—Sundew.

QUESTIONS

1. *The food of human beings depends directly or indirectly on the photosynthesis of plants. Show that this is true in respect of the following foods: bread, milk, eggs, mutton.*

2. *Three potted geranium plants, A, B and C, are put into a dark cupboard for two days. Then they are treated as follows for three days: A is put beside a window under a bell-jar, B is put beside a window under a bell-jar and the bell-jar contains sodium hydroxide, C is left in the dark. Answer the following questions:*

(a) *Why were the plants put into the dark?*

(b) *How would you test the leaves of A, B, C for starch at the end of the experiment? What results would you expect? Account for these results.*

(c) *What changes take place in the composition of the atmosphere of the bell-jar containing A?*

3. *Describe the external and internal characters of any one leaf, and*

explain why it is particularly fitted to carry out photosynthesis. (*See also Chapter I.*)

4. *Answer all the parts :*

(*a*) *Devise an experiment to show that nitrates are necessary for the healthy growth of green plants. What is the use of the nitrates to the plant ?*

(*b*) *Account for the fact that, although plants are continually removing nitrates from the soil, natural vegetation, such as a wood, continues to flourish.*

(*c*) *The experiment in* (*a*) *would not work if you used a leguminous plant* (*peas or beans*). *Account for this.*

CHAPTER VIII

ANIMAL NUTRITION

Animals do not contain chlorophyll and so, unlike plants, they have no power of making use of sunlight energy to build up their own food. They obtain their carbohydrates, fats and proteins and other materials either directly or indirectly from plants (see Chapter VII, page 70).

Let us think of some definite examples of animal food. We ourselves are mixed feeders and our diet includes meat, fish, vegetables, fruit, bread, eggs and milk. Rabbits and squirrels are vegetarians, the former eating the leaves of many kinds of plants, the latter eating nuts as well. Farm animals are also vegetarians and, besides the grass of their pastures, these animals are given special vegetarian food such as oil cake, meal, peas, beans, mangolds, oats and clover. Weasels and foxes are carnivores and hunt rabbits, mice and birds for their food. Our own pet animals, cats and dogs, are largely carnivorous and thrive best when their diet includes a fair proportion of meat.

Now none of these solid foods is of any direct use to the animal concerned even though it may contain an adequate proportion of carbohydrates, fats and proteins. To begin with, the blood cannot transport insoluble materials and, before animal food can be used in the body, it must be made into a soluble state by being digested. Furthermore, the carbohydrates, fats and proteins in the food are not the same as the carbohydrates, fats and proteins found in the body. Before food can be used in the body it must be digested or broken down into its simpler constituents. These are absorbed into the body and re-combined into the particular patterns characteristic of the animal.

DIGESTIVE ORGANS

The digestive organs include the mouth, the alimentary

canal, the liver and the pancreas. The position of these various organs in the body was described on page 26, and alimentary canal, liver and pancreas of man and rabbit are shown in more detail in Fig. 43. You will notice that the liver contains a small bag called the **gall bladder.** The gall bladder communicates with the first part of the small intestine by means of the bile duct. The pancreas also communicates with the

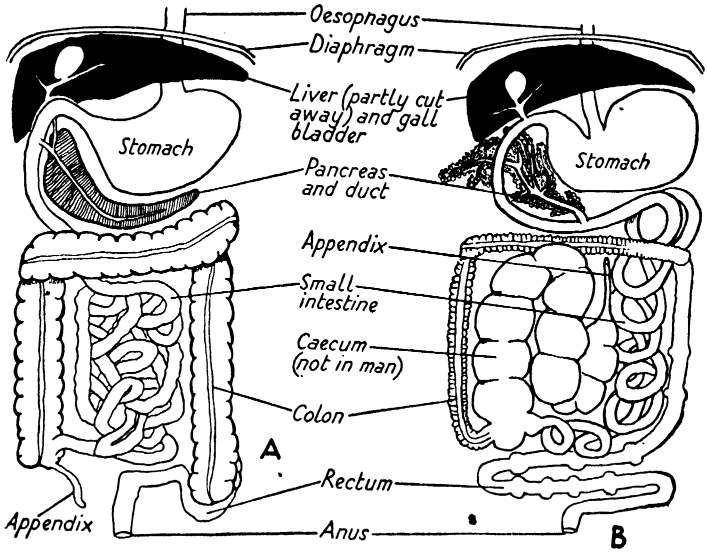


FIG. 43.—Digestive organs of man (A) and rabbit (B).
N.B.—Oesophagus = Gullet.

small intestine, for the pancreatic duct joins the bile duct and the two have a common entrance into the small intestine. In the rabbit the pancreas is a diffuse organ and has its own entrance to the small intestine.

All the parts of the alimentary canal have muscular walls and glandular linings. The outer muscles of the wall run parallel to the long axis (longitudinal muscles), and within these are circular muscles running round the wall (see Fig. 44). These muscles of the alimentary canal are not the same as the muscles of the body wall (see Chapter XI, page 134). Tripe consists of the muscular part of a calf's stomach, and this will

give you some idea of its consistency. The lining of the alimentary canal is usually corrugated and contains glands which secrete digestive enzymes.

DIGESTIVE ENZYMES IN MAN

Food is broken down into simpler substances by a veritable battery of digestive enzymes contained in the various secretions of the digestive organs. These secretions may be summarized as follows:

1. **Saliva,** produced from the salivary glands in the mouth, is a slightly alkaline liquid containing slimy mucus and an enzyme called ptyalin. The action of ptyalin is similar to that of diastase, for it breaks down starch into maltose.
2. **Gastric juice,** produced by the stomach, contains hydrochloric acid and two enzymes, pepsin and rennin. Pepsin and hydrochloric acid act together on all proteins and convert them into peptones, which are substances of intermediate complexity between proteins and amino acids. Rennin acts on milk, causing it to clot and thus retaining it in the stomach for the action of pepsin and hydrochloric acid.
3. **Pancreatic juice** contains sodium carbonate and enzymes, which break down fat (lipase), starch (amylase) and proteins (trypsin).
4. **Bile** is produced by the liver and is stored in the gall bladder. It contains bile salts (which have a physical action on fats) and bile pigments. The latter are really waste products, because they are composed of decomposition products of broken-down red blood corpuscles.
5. **Intestinal juice,** produced by the small intestine, contains an enzyme (erepsin), which converts peptones into amino acids. It also contains various sugar-splitting enzymes, which convert the more complex sugars into hexose sugars, and an enzyme which is essential for the working of the pancreatic trypsin.

You may like to do two simple experiments to show the action of ptyalin and pepsin respectively.

Experiment 23.—Collect some saliva in a test tube and add it to some very dilute starch solution (about 0·1 per cent.) in a test tube. Add some water to another tube of starch solution to act as a control. Have ready about twenty drops of iodine scattered on the surface of a white saucer or plate. At intervals of half a minute withdraw a little liquid from each of the test tubes by means of a glass tube and add it to one of the drops of iodine. At first the blue coloration, due to starch, is obtained with the liquid in both tubes, but gradually the liquid containing the saliva ceases to give the starch reaction, the

iodine remaining brown. Evidently the saliva has changed the starch into something else.

Now add some more saliva to a test tube containing more concentrated starch solution (2 per cent.). Allow it to stand in a warm place overnight together with a control tube containing starch and water without saliva. On the following day test the liquid in both tubes with Fehling's solution. The liquid containing saliva shows the presence of sugar, which must have been formed from the starch.

Experiment 24.—Coagulated white of egg is used as the protein and it is best used as a suspension in water. Heat some water in a beaker and, when the temperature is about 80° C., add some white of egg which has been slightly whipped with an equal quantity of water. Continue to heat and, as the temperature rises, the mixture gradually becomes opaque, because the protein coagulates. Do not allow it to boil. The white of one egg is sufficient for at least 1,000 c.c. of this suspension. Prepare three test tubes of this egg-white containing, respectively, pepsin, hydrochloric acid (two or three drops), pepsin *and* hydrochloric acid ; a fourth tube contains egg-white alone. Put the tubes into a beaker containing warm water at body temperature (36° C.). The contents of the tube containing egg-white, pepsin *and* hydrochloric acid gradually becomes quite clear because soluble peptones have been formed from the protein. The contents of the other tubes remain opaque ; neither pepsin nor hydrochloric acid alone can act on protein.

THE DIGESTION OF A MEAL IN MAN

Let us consider a simple meal consisting of beef, potatoes and cabbage, followed by fruit. This meal contains, among other things, proteins (particularly in the lean part of the beef), fats (particularly in the fat of the beef), starch (chiefly in the potatoes), cellulose (in the potatoes and cabbage), sugars (in the fruit) and various mineral salts (particularly in the cabbage). Also, the meal contains minute traces of certain vitamins. Unlike proteins, these vitamins do not build up tissues, and unlike carbohydrates and fats they are not used for storing ; nevertheless, the minute quantities of vitamins are essential for healthy development (see page 101).

In the Mouth.—In the mouth the food is chewed into small pieces and, at the same time, it is mixed with saliva. The mucus of the saliva lubricates the food so that it is easier to swallow and, at the same time, ptyalin starts to act on the

starch in the potatoes. However thoroughly you chew your food, the amount of starch digestion in the mouth is of little significance. Far more important is the conversion of the food into a pulpy mass by mastication aided by saliva. It is easy for the various digestive juices of the alimentary canal to permeate a soft pulp and to work on it, but food in the form of a compact mass could not be easily attacked.

When you swallow food the pulpy mass is forced into the gullet. Actually, the back of the mouth communicates with the wind pipe as well as with the gullet, and, during hurried eating, small particles of food may 'go the wrong way' and get into the wind pipe. Then you choke and cough until the particles are dislodged. Choking is rare because the entrance to the wind pipe is normally closed during swallowing by a little flap. Notice that when you swallow you must automatically stop breathing.

In the Gullet.—The pulpy mass of food is propelled along by an action called peristalsis. This consists in the alternate contraction and relaxation of the longitudinal and circular muscles. The circular muscles contract, thus making the tube narrower, so that it grips the food and pushes it onwards into a wider part of the tube, where the circular muscles are relaxed and the longitudinal muscles are contracted. Now contraction of the circular muscles takes place a little farther down the tube in the wider part where the food has been pushed, and so it is propelled a little farther. Peristalsis has the effect of pushing the food along rather as tooth-paste is squeezed along a tooth-paste tube. No digestion takes place in the gullet although the ptyalin of the saliva may continue to act on starch.

In the Stomach.—The stomach walls make very powerful muscular movements which drive the food from one end to the other and back. During this time it is thoroughly churned up with the gastric juice. The action of salivary ptyalin continues until the mass is penetrated by the gastric juice and then the hydrochloric acid makes it impossible for the ptyalin to work. Pepsin and hydrochloric acid together start to attack the proteins in the lean of the meat and break them

down into peptones. With this particular meal rennin has no action since there is no milk.

After about an hour in the stomach the ring of muscle guarding the entrance to the small intestine relaxes periodically and every time there is an opening a small quantity of food is forced through it. Churning continues in the stomach and it is not for another two or three hours that the stomach is emptied of that particular meal. Thus, one particular meal is in the stomach for about three or four hours. By that time you are probably about to take the next meal, so that the stomach gets very little rest, except during the night.

You may be wondering how it is possible to give times for the various stages in digestion. They are measured by taking X-ray photographs at intervals of the digestion of a meal to which bismuth nitrate has been added. X-rays cannot pass through bismuth nitrate, and hence the part of the alimentary canal containing the meal will appear black in the photograph.

In the small intestine.—After being in the stomach the meal has the consistency of rather thin porridge and, in this form, it is squirted at intervals into the duodenum where it meets immediately the pancreatic juice and bile. Both these juices are alkaline in reaction and the alkaline reaction puts a stop to the work of pepsin.

So far, only starch and proteins have been attacked; fats are quite untouched. The warmth of the stomach usually causes the fat to melt into large liquid drops. The bile salts have a very important physical action on these drops, causing them to break up into a large number of very small drops, so that they form an emulsion. The process is called emulsification, and you will see that it helps the subsequent action of the fat-splitting enzyme, which can act much more easily on the large surface area presented by the many small drops rather than on the large drops, the inside of which would not be in contact with the enzyme. The fat-splitting enzyme concerned is lipase from the pancreatic juice, which splits up the fats into glycerol and fatty acids. The fatty acids immediately combine with the sodium carbonate of the pancreatic juice to form sodium salts. These sodium salts are of course

soaps; perhaps it is just as well that there are no taste organs in the small intestine! It is possible to imitate the action of the bile salts on fats by a simple experiment.

Experiment 25.—Take two test tubes, one half full of water and the other half full of sodium hydroxide solution. Add a few drops of oil to each and shake thoroughly. Notice that in the tube containing water the oil separates at once and floats on the top, while in the tube containing sodium hydroxide a white emulsion is formed.

Now let us see what happens to the proteins and starch. Proteins which escaped digestion in the stomach are attacked by trypsin in the pancreatic juice and broken down into amino acids, while peptones formed in the stomach are turned into amino acids with the help of erepsin in the intestinal juice. The potato starch is turned into maltose by the action of pancreatic amylase, and then the maltose, together with any sucrose (either in the fruit or sprinkled on the fruit), are simplified into hexose sugars by the sugar-splitting enzymes in the intestinal juice.

X-ray photographs show us that the meal takes at least twelve hours before all of it has left the small intestine. During this time it is moved along by peristalsis, and there is also another type of muscular movement due to the constriction of the tube at intervals. The places of constriction are constantly changing, and the effect on the food is a sort of chopping movement, whereby it is thoroughly mixed with the various digestive juices.

Now let us summarize what has happened to our meal by the time the digestion in the small intestine is complete. The proteins from the lean part of the meat are all in the form of amino acids, the fatty part of the meat is in the form of soaps and glycerol, the carbohydrates of the potatoes and the fruit are in the form of hexose sugars. All these products of digestion are soluble materials. Other substances in the meal have not suffered any change; the cellulose structural materials in potatoes and greens remain as an insoluble residue. The mineral salts of the vegetables have not been attacked, but these are chiefly in a soluble form. As far as we know, the

vitamins in the meat and the fruit are not changed by digestion; they also seem to be soluble materials.

The lining of the small intestine has thousands of slender finger-like projections called villi (Fig. 44). Each villus contains a network of capillaries and a central lymphatic vessel called a lacteal. The villi are the absorbing organs of digested food and all the soluble materials pass into them. It seems

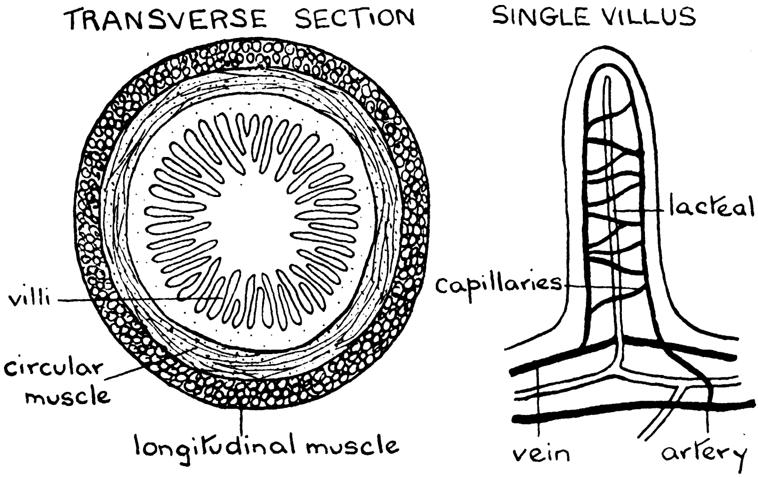


FIG. 44.—Structure of small intestine.

that absorption is not a merely passive filtration, there is some active force of absorption, but the mechanism of this is not known. Amino acids, sugars, mineral salts, water, and presumably vitamins also, pass into the blood vessels. The absorption of soaps and glycerol is rather a mystery. The lacteal contains abundant fat droplets which have presumably been formed from the soaps and glycerol; but in what form they get into the villus is not known.

In the large Intestine.—At intervals small quantities of residual matter are squirted into the large intestine. The residual matter consists of the undigested cellulose and water, together with bacteria; it is a brown liquid, and its brown colour is due to the bile pigments. The bacteria were originally taken in with our food, for very little of our food is in a sterile

condition; in the warm alimentary canal, where there is abundant food supply, they increased and multiplied exceedingly, so that by the time the undigested residue reaches the large intestine the original few bacteria have become millions.

The brown liquid is passed by peristalsis up the ascending colon, across the transverse colon and down the descending colon (Fig. 43). During this time water is gradually absorbed from it by the blood vessels in the intestine wall, so that by the time the residue enters the rectum it is in the form of a brown solid. The passage through the large intestine takes about sixteen hours or more and, at the end of this time, forceful muscular action at the end of the rectum drives the solid residue (or faeces) out at the anus. This muscular action is under voluntary control. You will notice that only the beginning and end of the long process of digestion comes within our consciousness or within our voluntary control, viz., chewing in the mouth and getting rid of faeces. All the other processes go on without our knowledge; the rhythmic muscular movements of peristalsis, churning and chopping proceed without any voluntary control. This is a great advantage, for what a nuisance it would be if you had to pull yourself up in the middle of playing cricket or watching a film and devote all your energies and attention to digesting your dinner.

Getting rid of undigested residue is an essential process which ought to happen regularly. Our meal takes 30–40 hours to go through the whole alimentary canal, and so every day, when we rid ourselves of undigested residue, we are getting rid of the remnants of food taken 30–40 hours ago. Of course, a light meal, such as a snack, does not take nearly so long to digest. Getting rid of undigested residue is sometimes difficult because of deficient muscular movements in the alimentary canal; we suffer from constipation and our residues become lodged. The cellulose in our food is hard and insoluble and acts as a stimulant to the muscles of the alimentary canal, so that they contract more forcefully and drive the food along, thus preventing constipation. This cellulose is called roughage. Several patent laxatives contain a good deal of chaffy material in the form of bran and this also acts as roughage.

WHAT HAPPENS TO THE DIGESTED FOOD

We have seen that potatoes, meat, greens and fruit are broken down during digestion into simpler materials, and that all of these, except fats, are absorbed into the blood in the capillaries of the small intestine. The capillaries gradually join together into veins and these unite into the portal vein which goes to the liver. In the liver the portal vein breaks up into capillaries again so that the soluble substances in them are brought into intimate contact with the liver tissues. Digested materials all go through the liver before they are supplied to the rest of the body and, indeed, the liver almost acts as a kind of sorting house. A great deal of chemical activity takes place within it.

Much of the absorbed sugar is removed by the liver cells and turned into the insoluble storage carbohydrate, glycogen. Blood reaching the liver from the small intestine has a high sugar content ; blood flowing away from the liver has a normal sugar content of 0·1 per cent. In the various tissues, some of the sugar is removed, either to restore the glycogen reserves in the muscles which have become depleted during respiration (see Chapter IX), or to be converted into fat and stored as such under the skin. These removals of sugar from the blood are made good by the liver which converts some of its glycogen into sugar. The liver acts as a carbohydrate reserve from which sugar is supplied to the body as it is needed. It has been found that the control of the sugar content of the blood exerted by the liver depends on the presence of a certain chemical substance called insulin. This chemical controller or hormone is actually produced by the pancreas and reaches the liver and other organs via the blood. Some unfortunate people produce insufficient insulin, so that glycogen storing either in liver or muscles becomes impossible ; the sugar content of the blood is abnormally high and much of the sugar is excreted in the urine. Such people suffer from the disease called diabetes ; they have no power of storing reserves from the food they eat.

The liver is concerned with the amino acids reaching it in

the portal vein. A proportion of these continues on in the blood stream and is used to build up proteins, either in the repair of ordinary wear and tear of tissues, or to make new tissues in growing children. The rest of the amino acids are retained by the liver and broken down. The nitrogenous part of the amino acid is converted into the waste substance urea, which is excreted. Thus, much of the protein we eat never reaches the tissues but is excreted as a waste substance. Nevertheless, the amino acids which do reach the tissues are vital to the body ; no other substances can make the proteins of protoplasm.

As far as we know, the mineral salts of the food are not affected in their passage through the liver, but pass on to the various tissues where they serve important functions. Calcium and phosphorus are both essential elements for building bones and teeth, both of which contain calcium phosphate. Iron is an essential constituent of the hæmoglobin of the blood. Various mineral salts, such as sodium chloride and potassium chloride, are necessary to maintain the composition of the plasma and of the lymph. The body rids itself of excessive mineral salts in the urine and in sweat (see Chapter X).

The uses of the vitamins in the absorbed food are described in the next section, while the uses of water were given in Chapter IV, page 41.

The fats of the absorbed food are not taken into the blood capillaries but into the lymph vessels. They are transported in the lymphatic system to the place where it joins the large vein in the neck. Thereafter they are in the blood stream, from which they are removed and stored under the skin.

THE DIET OF MAN

Now that we have seen what happens to his food, let us decide what sort of food man ought to eat. Among other things, his diet must provide him with energy. It is quite possible to calculate the energy requirements of a man or woman during 24 hours, and the value varies with the sort of work the man or woman does. We take the large Calorie as our unit of energy. A man in a sedentary occupation needs

3,000 Calories, a woman in a sedentary occupation 2,500 Calories, while a man doing heavy manual labour, such as mining, needs at least 4,500 Calories. The energy available in the food may be measured by burning it and estimating the heat output. The values obtained have to be reduced slightly to allow for the fact that no food is ever completely absorbed. After this adjustment it is found that by eating 1 gm. of carbohydrate the body is provided with a store of energy of 4 Calories; similarly, 1 gm. of protein provides 4 Calories, while 1 gm. of fat provides 9 Calories. Theoretically, the energy requirement of man can be met by carbohydrate, fat or protein, taken either singly or together. In practice, it is found that a balanced mixture of the three gives the best results. A balanced diet for a sedentary adult worker should contain 125 gm. protein, 125 gm. fat and 400 gm. of carbohydrate. The diet of a boy or girl between 12 and 21 should contain much the same quantities, for although the total size of the body is smaller, extra energy is required for growth. The diet of many people contains insufficient protein and fat as compared with carbohydrate.

Protein in the diet serves another purpose besides giving energy, for it is the amino acids formed after digestion that build up new protoplasm. In children and adolescents who are still growing the need is obvious, but, even in adults, a certain amount of body building is essential to replace wear and tear. The 125 gm. of protein given above includes enough for body building, provided that the proteins are of the right quality. In Chapter VI we said that there are 22 amino acids and that a selection of these is found in each protein. Now 12 of these amino acids are essential for building up protoplasm, the other 10 are useless. Proteins containing all the essential 12 amino acids are said to be first-class proteins. Animal proteins of all kinds found in meat, fish, eggs and milk are first-class proteins. Proteins relatively poor in the essential amino acids are second-class proteins. Strict vegetarians who do not eat eggs or milk, require much more than 125 gm. of protein in their daily diet.

Mineral salts are essential in the diet for the reasons we

discussed in the last section. Calcium salts are obtained from green vegetables and from milk. Phosphorus is obtained in certain proteins ; iron salts are provided in green vegetables and in meat. Green vegetables contain also potassium chloride. Sodium chloride is added to the food as such or is used in the cooking.

Until the beginning of this century there was some expectation of our being able to produce a synthetic diet, possibly in a compressed form, consisting of the necessary amounts of carbohydrates, fats, proteins and mineral salts. If sufficient water were drunk this diet was thought to be adequate. However, it was realized that the various movements of the alimentary canal, which aid digestion, would not occur if food were entirely in compressed tabloid form, for the movements are stimulated to occur by the presence of bulky food containing roughage. The synthetic diet would have to contain roughage. However, even the addition of roughage did not make a satisfactory diet, and it was realized that there are other essential constituents of diet than carbohydrates, fats, proteins, mineral salts, roughage and water.

In the early years of this century Sir Frederick Gowland Hopkins experimented on the feeding of rats on a synthetic diet. He found that young rats did not grow on this diet, but if a very small quantity of milk was added the rats thrived and grew normally. The amount of milk added was too small for its carbohydrate, protein and fat value to be of any significance. The effect was due to small traces of some essential substance which controlled growth. Later, this essential substance was called a vitamin. Meanwhile in Java, experiments were made on feeding birds on polished rice (the main food of the East). These birds suffered from a nervous complaint, involving paralysis, very similar to the disease beri-beri which was so prevalent among rice-eaters. By adding a small quantity of husks to the polished rice the birds recovered, and it was obvious that the husks contained a vitamin necessary for preventing beri-beri. The importance of fruit juices for health had been known for a very long time, and it was realized that the bleeding disease scurvy, so prevalent among sailors in the

sixteenth and seventeenth centuries, was due to lack of fresh fruit. A supply of lime juice on board ship prevented scurvy, and it seemed that fruits contain a vitamin necessary for preventing scurvy.

Several vitamins are needed in the diet, albeit in small quantities, in order to maintain health. Since the preliminary investigations there has been a tremendous amount of research work on vitamins, and now at least six are well known, and some of them have been prepared in a pure state. The existence of about ten others has been established. They are still known by the letters of the alphabet. Vitamin A is associated with animal fats, and is found particularly in milk, butter and liver oils. It is the growth vitamin discovered by Hopkins, and in its absence children do not grow properly. In adults, its absence leads to a hardening of the membranes of the eyes and also to inability to see in dim light (see Chapter XI, page 127). The human body has some power of making Vitamin A from the orange plant pigment carotin, hence the beneficial effects of eating carrots. Vitamin D is found in much the same foods as Vitamin A, viz., animal fats. Its presence is necessary for proper bone and teeth formation; it seems to affect the laying down of calcium phosphate. In its absence children develop rickets and have poor teeth which decay easily. In adults suffering from lack of Vitamin D, there may be softening of the bones. In the presence of sunlight the body can make its own Vitamin D from a certain fat (ergosterol) found in the skin. The ultra-violet rays of sunlight are responsible for the conversion.

Vitamin C is found particularly in fruit and vegetables. Prolonged heating destroys it and hence fresh fruit and vegetables are richer in the vitamin than cooked fruit and vegetables. Scurvy is comparatively rare, but scurvy and sub-scurvy have been reported during the war. Also, much slight ill health is due to deficiency in Vitamin C. Its positive action in the body is thought to be connected with respiration.

Vitamins B1 and B2 are widely distributed in peas, beans, yeast, marmite, whole meal, eggs, milk; in fact most natural foods contain them. Both are thought to be concerned with

the maintenance of the nervous system. Absence of B1 leads to the nervous disorder beri-beri.

Vitamin E is found in many foods, including milk, cereals and meat. In rats, its absence leads to inability to breed successfully. Its effect on man is not known.

Of all the various vitamins, C, D and A are likely to be deficient unless the diet is carefully planned to include an adequate supply of animal fats and milk (Vitamins A and D) and of fruit and vegetables (Vitamin C). The other vitamins are so widely distributed that in normal mixed feeding it is almost impossible to avoid them.

DIGESTION IN GRASS-EATING MAMMALS

In this chapter we have discussed nutrition in man. In other mammals digestion is by no means exactly the same, and vegetarian animals, in particular, show marked differences.

If you have seen the digestive organs of a rabbit you will have noticed the long wide tube branching off at the junction of small intestine and colon. This tube is called the caecum, and food is shunted up into this organ before it goes to the colon. In the caecum a good deal of cellulose digestion goes on by the agency of bacteria which are taken in with the grass or other vegetable food. In all grass-eating animals cellulose digestion is possible, and this is just as well, since such a large proportion of vegetable food consists of cellulose. Cellulose is digested into sugar which is absorbed into the blood. In grass-eating animals, digestion is by no means completed in the small intestine.

In cows and sheep, cellulose digestion takes place by the agency of bacteria in an enlarged bag, or rumen, between the gullet and the true stomach. Food is cut off in large pieces and bolted without mastication into the rumen. Here cellulose is digested and the food is softened. Then the softened mass is regurgitated into the mouth where thorough mastication takes place. This is familiar to you, for you have certainly seen these animals chewing the cud. When masticated the food is passed into the true stomach and digestion proceeds normally.

QUESTIONS

1. *Trace the digestion of a snack of bread and cheese. Name the chief substances formed after digestion.*

2. *Answer the following :*

(*a*) *Describe the villi of the small intestine and explain how absorption takes place.*

(*b*) *What are the chief constituents of the brown liquid which passes into the large intestine of man? What changes take place as it passes along the large intestine?*

3. *What are the chief values of the following foods : eggs, milk, oranges, butter, brown bread, cabbage? For each, state the uses to the body after digestion.*

CHAPTER IX

RESPIRATION

THE ENERGY OF LIVING THINGS

Energy may be defined as the power to do work (see the *Physics* book in this series [1]). Like matter, energy cannot be destroyed and cannot be created, it can only be transformed from one form to another. The energy required to run trains, ships, cars and aeroplanes is derived from burning a fuel such as coal or petrol. Plants and animals need energy, for in some ways they may be regarded as very complex engines requiring energy to drive them. They use their food as a fuel by oxidising it to liberate the energy. This process is called **respiration**, and the food oxidized is usually sugar.

$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + \text{ENERGY}.$$

This equation represents merely a summary of a complex chain of actions.

Let us consider carefully the source of the energy which is set free by burning fuels. The sugar respired by living things is directly or indirectly derived from plants, and the energy set free from the sugar was originally derived from the sun in the process of photosynthesis. The energy to run engines derived from coal or petrol is also ultimately derived from the photosynthesis of plants, for coal consists of the remains of prehistoric plants and petrol is derived from petroleum which was formed by the compression of the remains of prehistoric animals (see the *Chemistry* book [2]). We may conclude that the energy of all fuels, whether the food fuels of living things or the fuels of engines, is derived ultimately from the sun. The energy was locked up in the fuel in the process of photosynthesis. It is released when the fuel is oxidized.

[1] *Physics*, W. Ashurst, uniform with this volume.
[2] *Chemistry*, A. W. Wellings, uniform with this volume.

Animals require energy for movement, to maintain the complex state of the protoplasm and to cause growth to take place. Warm-blooded animals also require energy to keep up the temperature above that of their surroundings. Plants also require energy for life ; they do not move or keep up a raised temperature, but they must maintain the state of the protoplasm and they must grow.

Thus respiration is an essential activity of all living things ; without the continuous release of energy during respiration life cannot be maintained. Living things respire all the time, and this applies to resting organs, such as stored potatoes, winter trees and sleeping dormice, as well as to very active organisms, such as opening buds and frisking lambs. Of course, the rate of respiration varies according to the activity of the organism ; the opening buds and the frisking lambs generate energy at a much greater rate than the stored potatoes or sleeping dormice.

It is more difficult to realize energy production in plants than in animals, for they are less active. But seeds which have started to grow (germinating seeds) are very active and serve as suitable material for school experiments on plant respiration. You may use them for an experiment to show that some of the energy produced in the respiration of plants is in the form of heat.

Experiment 26.—Set two handfuls of wheat grains or one handful of pea seeds to germinate on wet filter paper (as for Experiment 22). When the roots have just appeared transfer them into a thermos flask containing a little damp cotton wool at the bottom. Put a thermometer into the flask and then wrap cotton wool round the thermometer in order to plug the mouth of the flask. Set up a control experiment with a similar flask containing damp cotton wool only or damp cotton wool and germinated seeds which have been killed by boiling. Record the temperature in both flasks and then examine the thermometers on the following day. The temperature in the flask containing the plants will have risen five or more degrees while that in the control flask is much the same as before. Of course, plants do not grow in heat-insulated surroundings and so the heat, generated in respiration under ordinary circumstances, is very quickly dissipated and the temperature of the plants does not rise above that of the surroundings.

CARBON DIOXIDE PRODUCTION AS AN INDEX OF RESPIRATION

To detect respiration in a plant or animal it is convenient to test for the carbon dioxide produced in the process. At one time or another you will certainly have tested for carbon dioxide in the air which you breathe out by blowing through a tube into lime water. The following experiment is a modification of this.

Experiment 27.—Using the apparatus shown in Fig. 45, put tube A into your mouth and suck through it six times. This has the effect of drawing ordinary air through tube B into the lime water. Now ordinary air contains very little carbon dioxide, and, after six sucks, not enough air has gone through for the lime water to become chalky. Now put tube B into your mouth and blow through it six times; your breathed-out air (expired air) bubbles through the lime water. Almost immediately the lime water becomes chalky because of the extra amount of carbon dioxide in expired air.

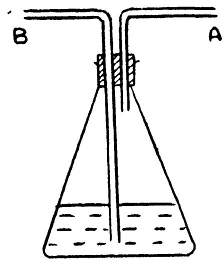


FIG. 45.

This experiment cannot be used for any other mammal; you will not be able to persuade a mouse to blow and suck to order. To test the air breathed out by a mouse much more elaborate apparatus is needed.

Experiment 28.—Use the apparatus shown in Fig. 46 and turn on the tap X of the aspirator A. As water drips out of the aspirator a current of air is drawn through the apparatus. This air enters at the tube P and bubbles through sodium hydroxide solution in bottle B to deprive it of carbon dioxide. Then the air bubbles through bottle C, containing lime water and, since the air is free of carbon dioxide, the lime water remains clear. Next, the air passes into bottle D, containing the mouse. The air which continues into bottle E contains some of the expired air of the mouse and the carbon dioxide contained in the air causes the lime water to become chalky.

This apparatus can be used to demonstrate respiration in plants also, for it can be repeated using germinating seeds in the bottle D. If you run the aspirator at the same rate as before you will find that it takes longer for the lime water in E to turn chalky; even actively growing plants do not respire as quickly as a mammal. You can also use the

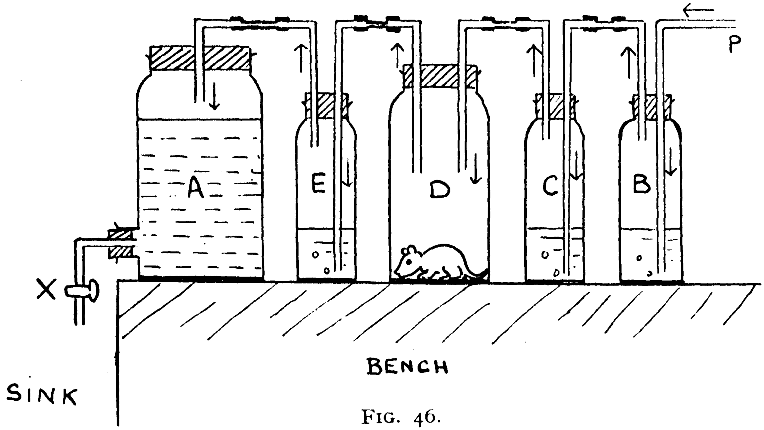


FIG. 46.

apparatus to demonstrate respiration in green shoots but, if you do this, you must be careful to prevent photosynthesis from taking place. During photosynthesis carbon dioxide is absorbed rather than given out. To prevent photosynthesis, wrap up bottle D in black paper so that the shoots are in the dark.

We have said that it is possible to compare the rates of respiration by comparing the times taken for the lime water to start going cloudy or to reach a certain degree of cloudiness. The same sort of experiment with more complex apparatus is used in research laboratories to measure the actual amount of carbon dioxide produced in a certain time by estimating the quantity of calcium carbonate produced in the lime water. The rate of production of carbon dioxide, estimated by such an experiment is an index to the activity of the organism.

THE SUPPLY OF FOOD FOR RESPIRATION

A continuous supply of food is required for the respiration of all living tissues. In an active plant this is supplied by the continual drift of sugar from the leaves to other parts of the plant (see Chapter VII, page 76). When resting organs, such as wheat grains or potato tubers, start to grow they use their food reserves, partly for the construction of new tissues and partly for respiration. Before being respired the reserves are converted into sugar. In respiration carbon dioxide and water

are formed and there is thus a decrease in the weight of solids in the growing seed or potato. Of course, the fresh weight of the germinated seed or potato is greater than the fresh weight of the resting organ, and this is because so much water has been taken in. However, the dry weight (which represents the weight of solids) decreases until the new leaves have been formed to manufacture more food. If germination takes place in the dark photosynthesis is not possible, even when the leaves have been formed, and the dry weight of the resulting plants is considerably less than that of the seed or tuber. You can show that wheat grains germinated in the dark decrease in dry weight.

Experiment 29.—Weigh two evaporating basins lined with filter paper and then put 40 wheat grains into each and re-weigh. Now damp the filter paper in one basin, cover it with another bowl and put it into the dark for about a week. Moisten the filter paper when necessary. The grains germinate into seedlings. Now put both evaporating basins into an oven at about 60° C. to evaporate all the water. After heating for about eight hours, cool in a desiccator, reweigh both sets, and then put them back in the oven and re-weigh at intervals until the weights are constant. The dry weight of the seedlings is considerably less than that of the original weight of the grains because of the loss of solids in respiration. The ungerminated grains show only a slight loss in weight because of the loss of the small amount of water contained in the resting grains.

In normal seedlings grown in the light there is an initial loss in dry weight, but this is soon made good by photosynthesis of the leaves.

Animal tissues contain food reserves in the form of glycogen, or fat, or protein, which were derived from the food which they have eaten and digested. All organs use their food reserves in respiration and it seems probable that sugar is formed first from the stores. Losses of food reserves are made good by abstracting more sugar from the blood stream and then this deficit in the blood is made up from stores elsewhere, particularly from the glycogen of the liver. The liver is the great reservoir of stored glycogen from which soluble sugar can be mobilized to the tissues according to the rate of respiration.

THE OXYGEN SUPPLY FOR RESPIRATION

Breathing in Mammals.—Respiration necessitates a continuous supply of oxygen to the tissues, as well as food. The oxygen is carried in the blood and this acquires its supply of oxygen from the lungs. All mammals have active breathing movements by means of which the air in the lungs is continually replenished.

Air is breathed in through the nostrils and, while passing through the nasal passage, it is warmed and moistened by contact with the epithelium lining the nose. The nasal epithelium secretes mucus, and also some of its cells have delicate protoplasmic outgrowths called cilia, which perform lashing movements and trap particles of dust in the air. The nasal passages lead to a cavity at the back of the mouth, the pharynx, which has openings leading to the gullet and to the wind pipe or trachea.

The windpipe (or trachea) has stiff cartilage hoops in its walls which prevent it from collapsing. It is lined by epithelium cells with cilia similar to those lining the nose. The upper part of the trachea is enlarged as the larynx, or voice-box ; this contains the vocal cords. The lower part of the trachea forks into two **bronchi**, which are similar in structure to the trachea itself, and each bronchus branches many times into the ramifying **bronchioles** of the lungs (Fig. 47). The smallest bronchioles are thin-walled tubes without any cartilage hoops. Each bronchiole ends in a cluster of thin-walled air sacs called **alveoli.** Between the alveoli are the numerous blood capillaries formed by the branching of the pulmonary artery.

Consisting as they do of much branched air tubes and blood vessels, the lungs are soft pink spongy structures. Some of you will be familiar with their appearance because ' lights ', sold as cat's meat, consist of lung tissue. In normal times it is easy to buy a pair of lungs from the butcher with the trachea attached. The lungs fill up the greater part of the thorax cavity, they are covered externally by a thin slippery sheet of connective tissue, called the pleura, and another sheet of this tissue also lines the thorax wall and the diaphragm. Between

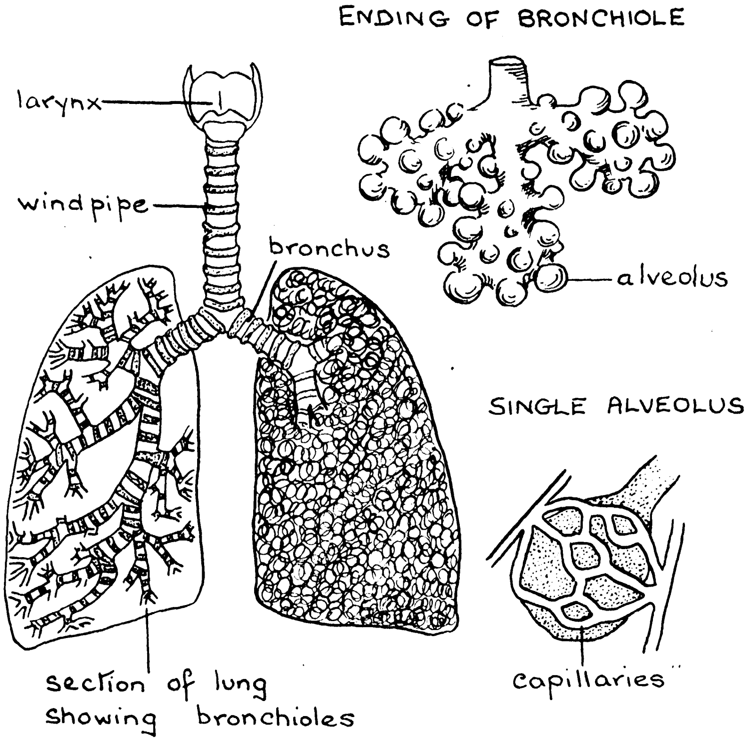


FIG. 47.—Lungs.

the two sheets of pleura is a small amount of liquid, the pleural fluid.

Now air does not go in and out of the lungs without something happening to cause a flow of air first in one direction and then in the other. What exactly happens when we breathe? If you place your hands round the sides of your chest and draw in a deep breath you will find that the ribs move. Movement of the ribs is one cause of breathing. Another cause is the movement of the diaphragm, and you can find out how the diaphragm acts in a very simple experiment.

Experiment 30.—Fit up the apparatus shown in Fig. 48. The rubber sheeting tied over the end of the bell-jar represents the diaphragm.

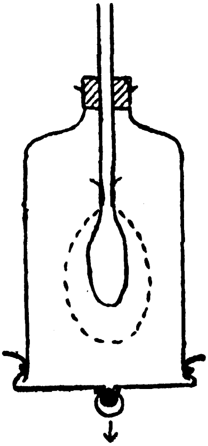


FIG. 48.

It has a small stone tied into it so that it may be pulled up and down. Pull the rubber down and observe that the balloon inflates, then push it up again and observe that the balloon deflates. Remembering Boyle's law (*Physics* book [1]), you will be able to explain the action. When the rubber is pulled down the volume of air inside the bell-jar increases and therefore its pressure decreases. The atmospheric pressure outside will thus force air down the tube and inflate the balloon. You must not compare this apparatus too closely with the lungs ; there is far too much space between the balloon and the bell-jar, and, moreover, this space should be filled with liquid if it was a faithful imitation of the pleural cavity. Further, the model cannot include anything representing the ribs. However, it is useful in showing how the diaphragm acts in breathing.

Now let us see exactly how the diaphragm and ribs act during breathing in or **inspiration.** The muscles of the dome-shaped diaphragm contract and thus the organ flattens and moves downwards. At the same time the muscles between the ribs contract and pull them upwards and outwards (see Fig. 49). The ends of the ribs are attached to the breast bone (or sternum) which is pushed outwards as a result of the movement of the ribs. All these movements have increased the capacity of the thorax and there is not enough pleural fluid to fill the extra space, there is a region of low pressure round the lungs. Immediately, atmospheric pressure drives extra air through the nasal passage to the pharynx and into the trachea and the lungs so that they inflate and fill the extra space in the pleural cavity. Breathing out or **expiration** consists in a reversal of these happenings.

It is possible for air to enter the pharynx and trachea via the mouth instead of via the nasal passages; in fact, if the mouth is open this is likely to happen. It is not a desirable procedure since the inspired air does not become warmed, moistened and purified to the same extent as in the nasal passages.

[1] *Physics*, W. Ashurst, uniform with this volume.

Breathing is caused by movements of the diaphragm and of the muscles between the ribs, and breathing exercises of various kinds are designed to work either the diaphragm or the rib muscles. Artificial respiration as applied to people who have ceased to breathe (because of drowning or for some other cause) consists in alternately compressing and releasing the muscles of the thorax wall so that the lungs expand and contract. The rhythm of artificial respiration often causes the normal rhythm of the diaphragm and rib muscles to start again. The iron lung is a device for maintaining artificial respiration for long periods. The patient lies inside an iron casing which alternately compresses his chest muscles and then releases.

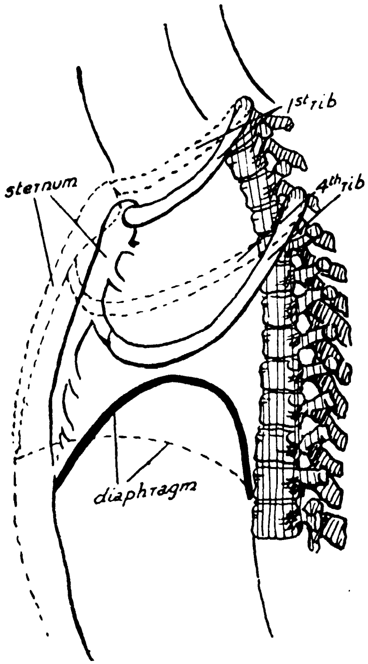


Fig. 49.—Diagram to show shape of chest before inspiration (complete line) and after inspiration (dotted line).

The Rate and Depth of Breathing. — The rate of breathing and depth of breathing vary greatly with the amount of activity. The normal rate of breathing is at about 15 times per minute. It is difficult to measure this because you so easily alter your rate of breathing simply by thinking about it. You may be interested to find out something about the volume of air breathed in and out, but here again you will find it difficult to maintain a normal depth of breathing.

Experiment 31.—Put a long rubber tube into a Winchester bottle and invert the bottle over water as shown in Fig. 50. Put the end of the rubber tube into the mouth and breathe in through the mouth. As air is sucked out of the bottle, water rises to take its place. Pull

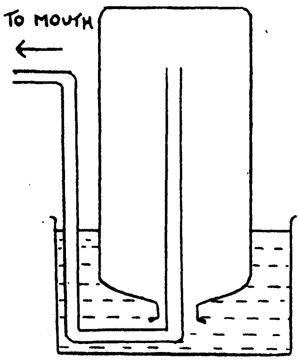


FIG. 50.

out the rubber tube, put a stopper into the bottle and remove it from the trough. Then measure the volume of water by pouring it out into a large measuring cylinder. You can repeat the experiment and find the volume of a forced inspiration when you breathe in as much as you possibly can. To find the volume of an expiration, either normal or forced, you must start with the bottle full of water and then breathe out through the rubber tube. Your expired air pushes some water out of the bottle, and when you remove the Winchester you must fill it up from a measuring cylinder of water in order to find out how much air you have breathed out.

The values for normal and forced inspirations and expirations vary considerably. An average for normal inspiration and expiration from a class is about 250 c.c.–350 c.c. : this is known as tidal air. The volume of a forced expiration will have convinced you that the lungs are by no means empty after a normal breathing out. In a forced expiration 1,750 c.c. of air can be breathed out ; of this only 250 c.c. represents tidal air. Moreover, at the end of a normal inspiration the lungs are by no means fully distended. In a forced inspiration 2,250 c.c. of air can be breathed in ; here again only 250 c.c. represents tidal air. The maximum capacity of the lungs will be given by the tidal air plus the extra air taken in during forced inspiration plus the extra air given out in forced expiration plus any air which still remains after a forced expiration. The value of the last volume can be determined with difficulty as 1,250 c.c. Hence the maximum capacity of the lungs is about 5,000 c.c. : a very considerable amount.

The rate and depth of breathing are controlled by a nerve centre called the respiratory centre in the hind brain. This centre is influenced by the concentration of carbon dioxide in the blood. If this is increased, as it will be during vigorous exercise, the blood flowing to the respiratory centre has a larger carbon dioxide content than usual and the centre causes

deeper and more rapid breathing. Conversely, if the concentration of carbon dioxide in the alveolar air is decreased below 5 per cent., the respiratory centre is depressed and breathing is slower and shallower. Occasionally breathing may cease for a few seconds. This happens if you take several very deep breaths without moving from your sitting position.

Composition of Expired Air and Inspired Air.—Now let us see how expired air differs from inspired air. At some time or the other you have certainly breathed out on a window-pane and seen the mist formed by the condensation of the water vapour in your breath. Expired air contains more water vapour than inspired air. You are also familiar with the fact that your breath is warmer than ordinary air; it has, of course, the temperature of the body, 36° C. or 98·4° F. From Experiment 27 you know that expired air contains more carbon dioxide than ordinary air. What about the oxygen content? To find out something about this it is essential that at least ten people do the experiment.

Experiment 32.—Put a rubber tube under a beehive shelf in a trough of water up into a gas-jar full of water (Fig. 51). Now blow out through the tube until the gas-jar is full of your expired air. Withdraw the rubber tube, cover the jar and put it on the bench. Now test it with a burning splint. The result will not be the same for all the ten people, the splint may burn momentarily or it may go out at once. This will convince you that expired air does contain some oxygen, otherwise the splint would always go out at once. The actual percentage is 14–16 per cent.

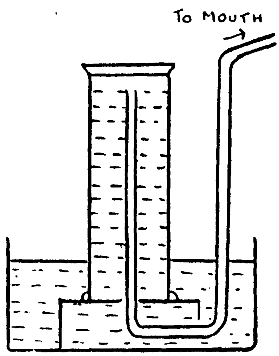


FIG. 51.

You can repeat the experiment and breathe in and out of the gas-jar about six times so that you are using the same air over and over again. This time when you test with a lighted splint it will certainly go out, since the oxygen supply will have gradually been depleted.

We can summarize the differences between expired air and inspired air in the form of a table which gives the approximate composition by volume of dry atmospheric air and dry expired

air. In the *Chemistry* book you will find methods given for finding these actual percentages of oxygen and carbon dioxide.[1]

	Inspired Air.	Expired Air.
Oxygen	20%	14–16%
Carbon dioxide . .	0·03%	4–6%
Nitrogen	80%	80%

The passage of Oxygen from the Lungs to the Tissues.—Breathing of air into the lungs is only one stage in the supply of oxygen to the tissues. The next stage is the transference of oxygen from the air in the lungs into the blood. We have seen that the capillaries in the lungs form a network over the alveoli. Red corpuscles are carried along these capillaries and their hæmoglobin has a great affinity for the oxygen in the alveoli. Between the alveolar air and the red blood corpuscles are only two thin walls, the alveolar wall and the capillary wall, and so the oxygen readily diffuses across in solution. In this process of absorption you will realize the significance of the very great surface area of the alveoli and of the capillaries. Absorption of oxygen is not the only change which goes on as blood circulates through the lungs. The concentration of carbon dioxide and water is much greater in the capillaries than in the alveoli and so these two substances diffuse in the reverse direction to the oxygen.

Blood returning to the heart from the lungs in the pulmonary veins is oxygenated, its red blood corpuscles contain oxyhæmoglobin. In this form blood is sent out via the aorta and branch arteries into the vast network of capillaries supplying every organ of the body. Now the concentration of oxygen in respiring tissues, such as muscles, is low and the oxyhæmoglobin decomposes into hæmoglobin and oxygen. The oxygen diffuses out into the lymph and thence to the muscles or other tissues

[1] *Chemistry*, A. W. Wellings, uniform with this volume.

where it is used to burn sugar and liberate its energy. At the same time the carbon dioxide formed in this oxidation diffuses in the opposite direction back into the capillaries. Blood returning to the heart via the veins is deoxygenated ; it is deficient in oxygen but contains excess carbon dioxide. In this form it is pumped by the pulmonary artery to the lungs where reoxygenation takes place.

Oxygen Supply in Plants.—Plants have no breathing movements and no circulatory system, the supply of oxygen to all the tissues depends on diffusion only. You will remember that plants expose a very much greater surface area to the atmosphere than mammals do, and also, there is an extensive system of internal air spaces, especially in the shoot system. The result is that none of the internal tissues in plants is very far removed from air supply.

Roots absorb oxygen dissolved in the water which passes into the root hairs. The maintenance of a supply of dissolved oxygen in the water films will depend on the oxygen content of the soil air spaces, hence the necessity for aerating the soil adequately.

Leaves and all green stems have a ready-made oxygen supply, for during the day-time photosynthesis is continually producing oxygen. Much more oxygen is evolved than is used up in respiration, and the excess accumulates in the intercellular spaces and gradually diffuses through the stomata into the air. In the light, green shoots absorb carbon dioxide and give out oxygen, and it is very difficult to detect respiration. In the dark, photosynthesis ceases and the drift of gases is in the opposite direction ; oxygen is absorbed from the intercellular spaces by the respiring cells until the concentration of oxygen in the spaces is less than that in the atmosphere, when oxygen diffuses in through the stomata. Carbon-dioxide produced in respiration accumulates in the spaces and then gradually diffuses out. Woody stems with lenticels absorb oxygen and give out carbon-dioxide by a process of diffusion through the lenticels.

You must remember that even though plants have no circulatory system, yet every living cell must be supplied with

oxygen if life is to continue. If you use actively growing seedlings you can demonstrate that they use up oxygen from the air.

Experiment 33.—Set wheat grains or pea seeds until they just start to germinate (see Experiment 26). Put some seedlings into a muslin bag containing some wet cotton wool and tie it to a glass rod in a gas-jar of air over sodium hydroxide solution (Fig. 52). Fit up a control experiment omitting the seedlings or using dead seedlings. In the gas-jar containing the live seedlings the sodium hydroxide solution gradually rises until it has filled about one-fifth of the space. In the control experiment the alkali does not rise. The rise is due to the using up of oxygen by the respiration of the seedlings; the carbon dioxide which was given out was absorbed by the alkali, thus causing a partial vacuum which is filled by the rise of liquid. Cover the gas-jar and put it on the bench. Then test the remaining gas with a lighted splint, which is immediately extinguished. This experiment is very similar to experiments on burning; a piece of phosphorus smouldering on a wire in a gas-jar of air would cause just the same result.

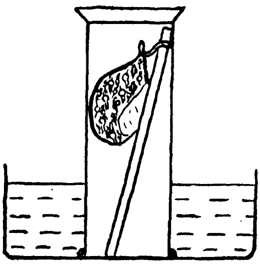


FIG. 52.

QUESTIONS

1. *Devise an experiment to compare the rate of carbon dioxide production in a frog and a mouse of comparable size. Account for the results.*

2. *How is the oxygen of the air in the lungs absorbed into the blood and distributed about the body?* (*See also Chapter V.*)

3. *'Plants respire only at night.' Criticize this statement and give a full account of the gaseous exchanges between a green leaf and the atmosphere in the course of 24 hours.* (*See also Chapter VII.*)

4. *The energy which enables you to run a race was ultimately derived from the sun. Justify this statement. Why are you breathless after running a race?* (*See also Chapters VII, VIII, XI.*)

CHAPTER X

GETTING RID OF WASTE

We have seen that a good deal of chemical activity goes on in both animals and plants, and it is only to be expected that certain waste materials will accumulate. If life is to continue satisfactorily, the body must get rid of these waste materials.

WASTE MATERIALS OF PLANTS

Water is continually being evaporated by the shoot system (see Chapter IV) ; this is a necessary consequence of exposing a large surface to the atmosphere, and we have seen that it has the effect of drawing into the root hairs more water containing the essential mineral salts in solution.

Oxygen is a waste product of photosynthesis in the green parts of the plant ; some of it is used in the respiration of the tissues, but the rest passes out through the stomata. Carbon dioxide, the waste product of respiration, is all used up in photosynthesis in the day-time. In the non-green parts (such as roots and older stems) carbon dioxide accumulates and passes out. During the night it accumulates and passes out in the green parts also.

WASTE MATERIALS OF MAMMALS

Animals have much more waste to get rid of than plants. To begin with, there is the residue of undigested food which is gradually forced along the large intestine and out at the anus (see Chapter VIII, page 97). In the sense that this residue has never penetrated the blood stream it has not been properly inside the body. The getting rid of waste materials formed in the actual tissues of the body is called **excretion**.

Waste materials to be excreted from the tissues include excess water, excess mineral salts, bile pigments, carbon dioxide and urea. We have seen that bile pigments are formed from broken-down hæmoglobin ; bile pigments are excreted via the bile

duct and join with undigested food. Carbon dioxide is a waste product of respiration. Urea is formed as a waste product of the breaking down of proteins or of amino acids. We saw in Chapter VIII (page 99) that some of the amino acids formed during digestion are immediately broken down in the liver. Proteins in the tissues are also broken down. In these decompositions the nitrogenous part is set free as ammonia. Now this is a toxic substance and would cause convulsions in the mammal if it accumulated. It is removed by the liver and converted into the harmless substance urea.

EXCRETORY ORGANS

The chief excretory organs are the lungs, kidneys and skin.

Lungs.—In the lungs carbon dioxide and water vapour are excreted, and we have seen in Chapter IX (page 116) how this happens.

Kidneys.—Fig. 22 shows the kidneys with their ureters leading to the bladder. The bladder communicates with a muscular tube, the urethra, leading to the exterior. In the male mammal the urethra is long and is encased in a special sheath projecting from the body, the penis (Fig. 79).

The tissue of the kidney is made up of a very large number of tiny winding tubes interspersed with blood capillaries. All the tubes communicate finally with the ureter. Excretory products pass into the tubes from the blood capillaries and the process seems to take place in two stages. First a liquid resembling blood plasma without its proteins is passed into the tubes. As this passes down the tubes sugar and some of the mineral salts are re-absorbed and at the same time more nitrogenous waste is added. The liquid which drips into the ureter is not of the same composition as that which entered the beginning of the tubule. The liquid which drips into the ureter is called **urine**, and its average composition is water 96 per cent., urea and other nitrogenous materials 2 per cent., inorganic salts 2 per cent. The salt content is considerably less in summer than in winter, for in summer more salts are lost by sweating than in winter. The kidneys not only get rid of nitrogenous waste and water, but they enable the

composition of the blood to be constant, particularly in respect of its salt and water content.

The urine drips into the bladder continuously, thus distending the walls. The entrance from the bladder to the urethra is guarded by a ring of muscle which is normally contracted and keeps the entrance closed. At intervals, the pressure of urine in the bladder becomes high enough to set up impulses which are conveyed to the central nervous system, whence impulses are relayed to the bladder, causing it to contract, and to the ring of muscle guarding the entrance to the urethra, causing it to relax so that the urine is released. In all except very young mammals, this action is under voluntary control.

The Skin.—The skin has several important uses of which excretion is only one. The outer part of the skin, or epidermis, consists of several layers of epithelum, the inner ones of which are living and the outer ones are horny and dead. The outer horny layers are continually being rubbed away and are replaced by divisions of the living cells below. The boundary between epidermis and the underlying dermis is a corrugated one (see Fig. 53), hence the pattern of lines which are visible from the outside and cause finger prints. The dermis consists of connective tissue within which are conglomerations of cells containing a good deal of stored fat. Hairs grow from hair follicles which are pockets of epidermis sunk into the dermis. At the base of each follicle is a knob of dermal tissue from which the hair is formed.

Sweat glands are much coiled tubes in the dermis communicating with ducts which lead up through the epidermis to the outside. There are nerves in the dermis and some of them communicate with sensitive cells ; one of the chief uses of the skin is that it contains important sense organs (see Chapter XI, page 130). The whole of the dermis has a rich blood supply ; capillaries are particularly abundant round the sweat glands. The epidermis has neither nerves nor capillaries and it is quite insensitive.

The excretory organs of the skin are the sweat glands. From the surrounding capillaries water and mineral salts diffuse into the glands. The solution exudes up the ducts to the outside

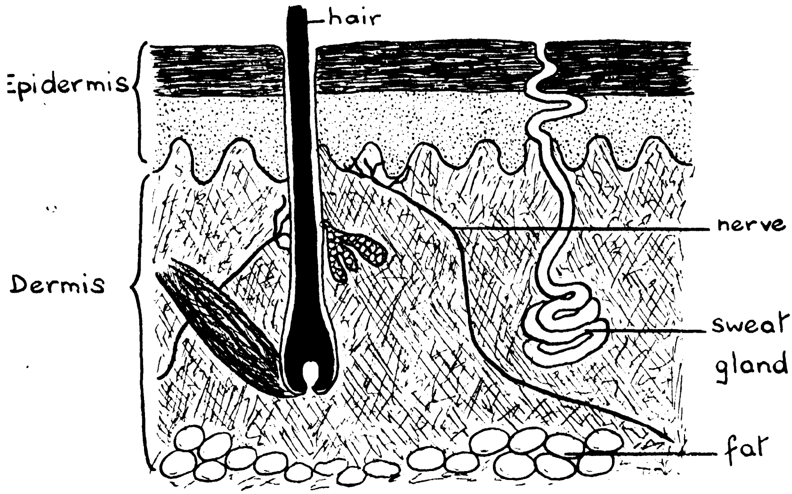


FIG. 53.—Section of skin. Blood vessels omitted.

and here the water evaporates, leaving the mineral salts as a residue. The evaporation of water requires latent heat, which is supplied by the skin ; sweating is one of the chief means of regulating body temperature. Sweating goes on all the time, but it is more pronounced when the body is generating a great deal of heat, as happens during violent exercise. Under these circumstances the capillaries round the sweat glands dilate, water and mineral salts are exuded at a much greater rate than usual ; so much so, that there is no time for the water to evaporate as soon as the liquid reaches the surface, and so drops of liquid accumulate on the skin. Moreover, salts accumulate on the outside of the skin ; after a race you can often taste salt by licking your lips or your arms. Sometimes the loss of mineral salts caused by excessive sweating is serious, because the blood is losing more sodium chloride and other salts than can be replenished by the food. Miners sweat a great deal, and sometimes they are given salty water to drink to quench their thirst in order to replenish some of the mineral salt loss.

Sweating is a most important method of temperature regulation in a mammal. The temperature of the human body in health is always 98·4° F. (36° C.). Respiration is continually

liberating energy from sugar and much of this energy is in the form of heat. The excess heat is used to evaporate water. The body also loses excess heat to the atmosphere directly by conduction, convection and radiation, and these processes will be increased when the surface blood vessels dilate, as they do during exercise.

The importance of suitable Clothes and Ventilation.—For normal health and comfort it is most essential that temperature regulation should operate smoothly. Clothes have a great influence on this. Direct loss of heat from the skin is to the layer of air round the body, thence to the clothes and so to the outside. Clothes vary in regard to their power of conducting heat ; wool entangles a good deal of air in its meshes and is a poor conductor of heat, while cotton has very little air content and is a fair conductor of heat. Woollen clothes retard heat loss, while cotton clothes promote it. The rate of sweating is also affected by the clothes. The sweat glands give off water vapour into the layer of air round the body and thence it diffuses through the clothes to the surrounding air. In addition, drops of liquid sweat are absorbed by the under-clothes. Woollen materials are very absorbent and give up the water slowly, hence woollen underclothes readily absorb liquid sweat but do not give it up fast enough to cause chilling. Cotton materials are quickly saturated with water and give it up as vapour very easily ; unless they are of the cellular type, cotton materials are not suitable for underwear.

Heat regulation in the body is also affected by ventilation. If the ventilation is inadequate the air has more carbon dioxide than usual, less oxygen, more water vapour and an increased temperature. Except in extreme conditions, when the oxygen content falls below 13 per cent. and the carbon dioxide content rises accordingly, the variations in oxygen and carbon dioxide have little effect. However, the increased humidity and the increased temperature have a marked effect. Direct loss of heat from the body by conduction, convection and radiation is impeded by the increased temperature of the surrounding air, while sweating cannot function normally because of the raised humidity. A device to secure movement of the air,

such as an electric fan, does not constitute adequate ventilation, but it does help matters, since evaporation of sweat will be favoured by moving air rather than by still air.

QUESTIONS

1. *What do you know of the position in the body and of the uses of* (*a*) *the liver,* (*b*) *the kidneys?* (*See also Chapter VIII.*)

2. *How is heat generated in your body? By what means is your temperature regulated to* 98·4° *F., whatever the external conditions? Discuss carefully the importance of* (*a*) *clothing,* (*b*) *ventilation in aiding temperature regulation.* (*See also Chapter IX.*)

3. *Describe and explain the changes which take place in the composition of the blood as it flows through* (*a*) *the lungs,* (*b*) *the kidneys,* (*c*) *the sweat-glands,* (*d*) *the liver,* (*e*) *the villi of the small intestine,* (*f*) *the muscles of the leg.* (*See also Chapters V, VIII, IX.*)

CHAPTER XI

ANIMAL BEHAVIOUR

If we are to understand how animals behave we must know how they are put into touch with their environments, for their actions consist largely in responses to stimuli caused by their environment. The sound of a distant gun-shot makes rabbits bolt for their burrows, the blazing summer sun makes the cat stretch itself out on the top of the wall, while the cow seeks shade under a tree. The responses of animals are due to their possession of receptors, effectors and nerves. **Receptors,** or sense organs, are sensitive to external stimuli. **Effectors** are the organs which actually carry out the responses, such as the muscles which bring about movement. Receptors and effectors communicate with one another by means of the nervous system. To take a concrete example, if you see a piece of waste paper on the floor you may walk towards it, pick it up and put it in the waste-paper basket. The receptor is the eye stimulated by light reflected from the piece of paper, the effectors are the various muscles concerned in walking and bending, and the eye was able to communicate with the muscles via the nervous system.

RECEPTORS

The human body has receptors sensitive to light, sound, certain chemicals, contact and temperature.

The Eye.—The structure of the eye is shown in Fig. 54. You will see that it has three coats—sclerotic, choroid and **retina**—and that the coloured part of the eye, or **iris,** is continuous with the choroid. The **lens** is slung from the region between the choroid and the iris by a circular suspensory ligament. Normally the suspensory ligament is taut and exerts a tension on the lens, thus reducing its curvature. The cavity of the eye in front of the lens is filled with a transparent liquid (aqueous humour) and the cavity behind the lens contains transparent jelly (vitreous humour).

Rays of light entering the eye through the pupil are focused

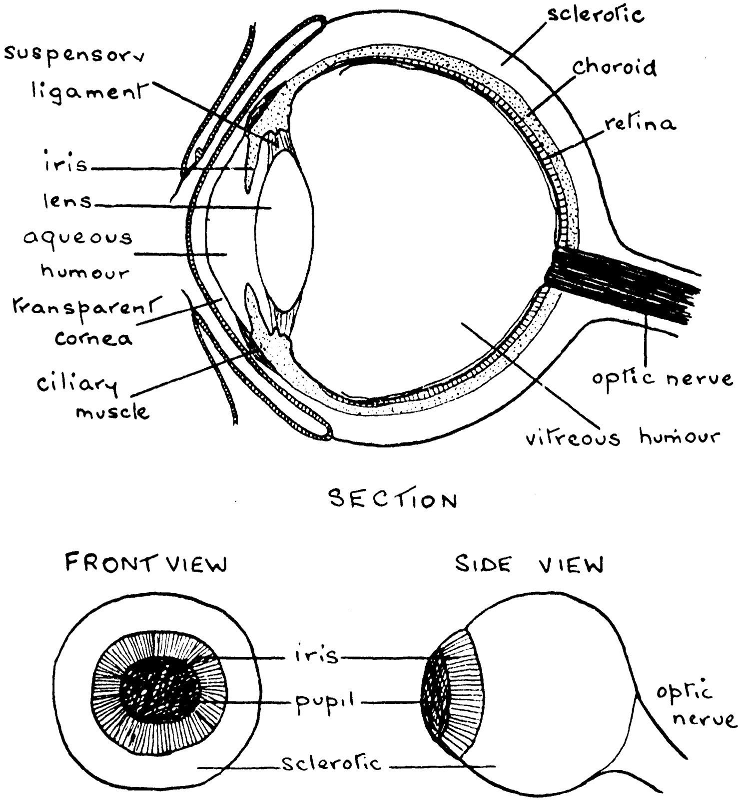


FIG. 54.—The eye.

by the lens to form an inverted image on the sensitive retina. In this action the eye resembles a camera (see *Physics* book [1]). Impulses are relayed from the retina to the brain by the optic nerve, but some adjustment takes place in the brain for the impression received is of the object in its erect position.

When at rest, the normal eye is able to see clearly objects at a distance of 15 feet or more, but, like the camera, some adjustment has to be made for near objects. In the camera, near objects are focused by increasing the distance between the lens and film. In the eye, the distance between lens and retina is fixed and near objects are focused by making the

[1] *Physics*, W. Ashurst, uniform with this volume.

lens more convex. This takes place with the help of the ciliary muscles, which form a circle round the edge of the suspensory ligament. They contract, thereby forming a smaller circle and slackening the suspensory ligament. Hence, the tension on the lens is reduced and it bulges, i.e., it becomes more convex ; this process is called accommodation. Sometimes the eye loses its power of accommodation, especially in old age or when a good deal of close work has to be done. When the person can see distant objects clearly but near objects are blurred he is said to be long-sighted. Then the rays of light have to be focused by a convex lens. You will find details of this correction of long sight and also of short sight in the *Physics* book.[1]

The muscles of the iris enable the eye to adjust itself to different intensities of light. In bright light the muscles contract, thus constricting the pupil. In dim light the muscles of the iris are relaxed and the pupil has its maximum size. Cats have a much larger range of pupil size than humans, in very dim light their pupils are very large. To an observer cat's eyes seem to shine in very dim light, this is due to reflection of light from the retina. The retina of the eye is stimulated in different ways by intense and dim light. Vision in dim light depends on the presence of a chemical called visual purple in the retina ; this is bleached in strong light but is formed again when the light intensity is reduced. When you go out from a brightly lit room into the night you cannot see anything at first and then gradually dim shapes, of trees and lamp-posts, become visible. The widening of the pupils is instantaneous and the time which elapses before you can see anything is the time required for the formation of visual purple.

The Ear (Fig. 55).—The ear lobes on each side of the head are the least important parts of the sound receptors. It is true that dogs, rabbits and donkeys can move their ear lobes so that the ear passage is directed towards the source of sound, but, in human beings, the ear lobes have not even this use. The ear passage is a crooked tube lined with glands which secrete wax. It ends at the ear drum, a circular-stretched membrane. On the other side of the drum is a cavity in the

[1] *Physics*, W. Ashurst, uniform with this volume.

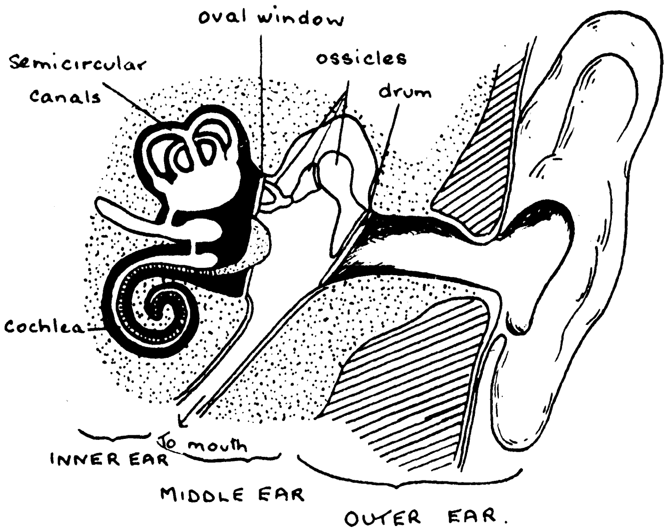


FIG. 55.—Section of the ear.

skull known as the **middle ear.** It contains air and communicates with the back of the mouth by a tube. By means of this communication with the mouth the air pressure in the middle ear is always the same as that of the atmosphere. A chain of three small bones stretch across the middle ear from the drum to a membrane on the far side called the oval window. On the other side of the oval window is the **inner ear,** a cavity in the skull filled with liquid. The inner ear contains a series of intercommunicating tubes. The shell-shaped cochlea contains the sound receptors, while the semi-circular canals are sensitive to the position of the body and are therefore concerned with maintaining equilibrium. The nerve entering the brain from the ear is supplied by two main branches, one from the cochlea and one from the semi-circular canals.

Sound waves entering the ear lobe are concentrated in the ear passage and set the ear drum into vibration. These vibrations are communicated to the chain of small bones which, in their turn, set the oval window vibrating. The vibrations of the oval window are transmitted to the liquid in the inner ear and thence to the cochlea. Among human

beings, there is obviously considerable variation in the degree of sensitivity of the cochlea or of the discrimination of the brain; some people can analyse orchestral music into its constituent notes much more easily than others. Moreover, range of sound waves appreciated by a human cochlea is not the same as that of other animals. It seems probable that dogs can hear notes of higher pitch than we can.

The semi-circular canals contain a liquid. When the head is moved the liquid is set in motion and this stimulates some sensitive cells in the swollen parts of the canals. From these, impulses pass along the nerves to the brain.

Sense Organs of Smell and Taste.—At the back of the nose are some sensitive cells, the olfactory cells, which are stimulated by the vapours of certain chemicals. We are able to smell solids and liquids if they give off vapours to which our olfactory cells are sensitive. All vapours and gases do not stimulate; for example, neither water vapour nor oxygen has any effect. Vapours which do stimulate our olfactory cells need only be present in very small proportion; thus, humans can detect many vapours when they are present as one part in several million parts of air. Dogs and other mammals can distinguish even lower concentrations than humans and they also seem to be sensitive to a larger range of chemicals than we are. This well-developed sense of smell enables carnivorous mammals to follow their prey by its scent.

Olfactory cells can also be stimulated by substances in the mouth. The nose communicates with the back of the mouth and hence vapours from substances in the mouth are able to reach the olfactory cells. By this means we can appreciate the differences between the various things we eat; actually we 'taste' our food largely by the sense of smell. If you have a bad cold the olfactory cells become covered with mucus and the vapours cannot reach them. Then you say you cannot taste your food, but actually this is an incorrect statement, you ought to say you cannot smell the food properly. It is possible to do an experiment on a normal person without a cold to show that the difference in the so-called taste of an apple and an onion is due to smell.

Experiment 34.—If you hold your nose you will easily tell whether you have a piece of onion or a piece of apple in your mouth, because your tongue is able to feel the smooth texture of the onion or the rough texture of the apple. Hence, it is necessary to arrange for material of similar texture to be put into the mouth ; and this experiment should be carried out as a sort of trick on somebody who is unsuspecting of what is being prepared for him. Send one of the class outside, while the rest of you prepare two lots of apple, one normal and one thoroughly rubbed with an onion. Now ask the victim to come in, shut his eyes and hold his nose. Tell him that he is going to be given some apple and then some onion and that you will start with two pieces of apple. Now feed him first with the normal apple and then the apple rubbed with onion. He is expecting onion to come afterwards and, as long as he holds his nose, the two pieces of apple will seem to be quite normal. Only when told to release his nose does he discover that he has been duped.

Actually there is a proper sense of taste as distinct from smell. The tongue has some collections of cells called taste buds which are sensitive to a few chemicals, but the range of sensitivity is very limited. Sensations of saltiness, sourness, sweetness and bitterness in foods are due to direct stimulation of these taste buds, and such sensations do not disappear when you have a cold. The sense of taste is much less sensitive than the sense of smell. Sweetness can only be detected as 1 part in 200.

Sense Organs of the Skin.—We have seen that the nerves of the skin end in sensitive collections of nerve cells (Chapter X, page 121). The cells are sensitive to contact and to difference in temperature, and are responsible for the sensations of touch, pain, heat and cold. The skin sense organs are of great value because they indicate to us at once the nature of our surroundings, and we are able to act immediately if the conditions are unfavourable. Life would be a very difficult affair without these useful indications of environment ; imagine how awkward it would be if your first consciousness of having touched a hot poker was the sight of a charred finger. Far from being a harmful thing, the sense of pain is of great importance to us, it enables us to steer clear of many dangers.

The sense of touch is highly developed in man. His various forms of manual dexterity, ranging from chopping wood to painting a picture, depend largely upon it. It is possible to

show that there are definite spots in the skin sensitive to touch and that the distribution of these spots varies in different parts of the body. A touch spot is of course a collection of nerve cells.

Experiment 35.—As in Experiment 34 it is best to carry out this experiment with an unsuspecting victim. Ask him to shut his eyes and tell him that you are going to touch him with a pair of dividers, sometimes using one point and sometimes both points. Ask him to tell you when he feels pricked by one point and when by two points. Start with the dividers at least half an inch apart, and if you try touching his finger he will tell you quite accurately whether he is touched by one or two. Now move the points nearer together and try again. If his statements are still accurate move the dividers almost together. When the points are very close your victim is unable to tell whether he is being pricked by two points or one; his answers are as often wrong as right. The collections of touch cells are localized, and, although they are thickly distributed in the finger, yet, with the dividers very close, it is very likely that only one touch spot will be stimulated. The distance apart of the dividers for accurate discrimination varies in different people, if your victim is an accomplished pianist you will find that he discriminates very accurately until the dividers almost touch.

Now try another part of the body, such as the front of the leg, middle of the back or tip of the tongue. You will find the leg and the back far less sensitive than the finger; the dividers can be quite widely separated before there is accurate discrimination. The tongue, on the other hand, is very sensitive indeed, more so than the finger.

Internal Receptors.—Your sum total of sensations includes not only stimuli from the environment but also stimuli from inside your bodies. You are aware not only that the sun is shining and the birds are singing but that your own body is in a relaxed state on the grass with your knees drawn up. Make no mistake about this; you can *feel* the position of your body and the degree of tension in the muscles. It is not just a case of remembering that you bent your knees; with your eyes shut you can feel the condition of your limbs and your trunk. These sensations are due to nerve endings in the muscles and joints called internal receptors.

Sense Organs and Consciousness.—You must be wondering how it is possible for you to control your mental processes when sensations due to the external and internal environment are

continually being generated. At this present moment why are you able to read this page and to use your powers of concentration to reason out what is meant by Animal Behaviour? Why are you not continually distracted by the warm sun, blue sky, class-room desks and pictures, smell of school dinner, distant sound of trains, feel of your clothes against your skin, degree of tension in your muscles and so on? The reason is that the conscious region of the brain is affected most by a change in sensations. As long as conditions remain the same, the sun, school dinner, trains and so on scarcely impinge on the conscious region of the brain. But if there is a sudden loud banging of a door or a cool wind suddenly blows through the class-room, you will be aware of it. It is when the environment is changing that sensations impinge more forcibly on consciousness. We have said that our sensations are a safeguard against danger, and it is just as well that when conditions are fairly equable our whole attention need not be directed to the environment. A new stimulus is disturbing at first, but, if it becomes a regular part of the environment, and is not too intense, it soon fades from consciousness. Traffic noises in a large town may be very disturbing to a visitor from the country, but to the people who live in the town they pass almost unnoticed. Similarly, the heat of the tropics seems overpowering to a new arrival until he becomes used to it.

Moreover, since the brain is conscious more of change in stimuli rather than of the actual quantitative value of stimuli, it is possible to accustom the body to increasing intensity of any one stimulus provided it is done gradually. If you run hot water gradually into a warm bath you can feel quite comfortable in a temperature which you could not possibly have withstood if you had stepped into it at first.

EFFECTORS

When the body responds to a stimulus it does so by means of its effectors. Usually the response is one involving movement and hence muscles are the chief effectors.

Muscles of the Limbs and Body Wall.—Some of the limb muscles were shown in Fig. 16, and the action of muscles in

bringing about movement at a joint was described. This action resembles that of a lever, the joint being the fulcrum, the muscular pull being the effort and the forearm being the load. You will realize that this type of lever has a mechanical disadvantage, for the effort is applied very near the fulcrum. On the other hand, the velocity ratio is less than one ; muscles have to exert a big pull but they work through small distances. Muscles contract in response to nervous impulses relayed into them from the nerves.

The muscles of the trunk wall are flatter than those of the limb but they work in much the same way. We must remember also that the tongue is a muscle and, in the human body, a very active one ; it is unlike other muscles because it is attached at one end only.

When the body is not moving you must not think that all its muscles are relaxed. Far from it. The position of the limbs and the trunk is controlled by opposing sets of muscles. The degree of bending at the elbow joint is controlled by the relative amounts of contraction of the biceps and triceps respectively, and similar considerations apply to every other joint in the body. Your standing and sitting postures have to be maintained by the appropriate degree of muscular contraction.

The proper training of all the body muscles is an important part of education. Without such training you are apt not to use your muscular power to the full. Some muscles are apt to be neglected, and, if this is so, they contract only with difficulty. Ease of muscular contraction depends on constant use.

Muscular work requires energy which is supplied by respiration, and, to continue working, muscles must have a continuous supply of food and oxygen. The food available is the glycogen, which is always stored in muscles. There is no such store of oxygen which has to be abstracted from the circulating blood. Careful investigation has shown that the process of muscular contraction is accompanied by the splitting of glycogen, first into glucose and then into lactic acid ; oxygen takes no part in this reaction. The part played by oxygen is that it oxidizes some of the lactic acid to carbon dioxide and

water, and the energy released from this process is used to build back the remainder of the lactic acid into glucose and then into glycogen. Hence, continuous muscular contraction involves a steady supply of oxygen in order to build back the glucose. As a rule the building back keeps pace with the splitting up, but, in strenuous exercise, such as running a race, the increased degree of contraction necessitates a great deal of splitting of glucose and, although breathing becomes deeper, the oxygen supply of the muscles is no longer adequate to build back all the lactic acid ; this gradually accumulates and, when the race is over, deep breathing continues for some time until all the excess lactic acid has been removed. The oxygen debt of muscles during strenuous exercise cannot accumulate indefinitely ; the presence of excess lactic acid causes fatigue in the muscles and their power to contract is gradually decreased. Only in the trained athlete can the muscles continue to work even in the presence of excess lactic acid ; to a large extent the man who wins the race is the man who can stand the biggest oxygen debt without giving in.

Other Muscles.—The muscles of the internal organs, such as the alimentary canal and blood vessels, are simpler in structure than the muscles of the body wall. These muscles have a slow rhythmic action, slow contraction followed by slow relaxation.

Heart muscle is peculiar to itself, for its action is not caused by nervous impulses ; as long as it is alive it will contract and relax. In a freshly dissected frog the heart is often beating although the animal was killed by destroying its brain. However, in the intact body, the rate of the heart beat is modified by the effect of nervous impulses.

Glands.—Muscles are not the only effectors in the body. Towards the end of the morning if you smell the dinner cooking your salivary glands secrete saliva ; in this case the salivary glands are the effectors. Also, the presence of food in the mouth stimulates the taste buds and the touch spots in the tongue, and again the effect is secretion of saliva. Similarly, the gastric glands secrete gastric juice as a response to the presence of food in the mouth.

Glands in general are collections of cells of special chemical

activity. Often the cells form complicated tubes and the tubes join into one main tube or **duct** through which the secretion is discharged. Other important glands with ducts are the pancreas, the liver and the mammary glands (in the breast). Some glands have no ducts and pour their secretions directly into the blood stream. Examples of these, such as the thyroid gland, pituitary gland and others will be considered at the end of this Chapter (page 145).

THE NERVOUS SYSTEM

The nervous system connects the receptors with the effectors. By means of your eyes you may see a piece of paper on the floor, but the muscles of your legs would never cause you to walk and pick it up unless the retina of your eye and the muscles of your leg were linked up by the nervous system. Just as a telephone caller cannot contact the person, to whom he wishes to speak, directly, but only through the exchange, so the eye does not communicate with the leg directly but only through the spinal cord and brain, which together constitute the central nervous system. By means of the nervous system all the various organs can affect one another's activities, and hence the body works smoothly and as a whole; in other words, the body is co-ordinated.

Let us consider the part played by the nervous system in causing the piece of paper to be picked up. The stimulation of the retina (the receptor) by light causes a series of changes, called **impulses**, to pass along the optic nerve towards the brain. These impulses going towards the central nervous system are called **afferent impulses.** In the brain these impulses generate another set of impulses to go along the nerves supplying the muscles of the trunk, arms and legs so that the appropriate muscles contract and the piece of paper is picked up. These other impulses passing outwards from the central nervous system are called **efferent impulses.**

Nerves.—Both the brain and the spinal cord have paired nerves communicating with them. The nerves from the brain, cranial nerves, issue through special holes in the skull, while the nerves from the spinal cord, spinal nerves, come out in the

spaces between the vertebrae. Between them these cranial and spinal nerves supply every organ in the body (Fig. 56).

In Chapter II, page 20, we learnt that cells of nervous tissue have several outgrowths. One of these, the nerve fibre or axon, is usually much longer than the others. A nerve cell, together with all its outgrowths, is called a neurone. Nerves consist of a very large number of nerve fibres; these are outgrowths from cells in or near the central nervous system, and they end in sense organs, or glands, or muscles. Any one nerve fibre conveys either afferent impulses, if it is connected with a sense organ, or efferent impulses, if it is connected to a gland or muscle. The nerve itself contains both afferent fibres and efferent fibres. Thus, the nerves of the leg have efferent fibres going to the various muscles, and afferent fibres supplying the sense organs of the skin and the internal receptors. If the nerve is cut, the organ supplied by that nerve is not only paralysed but there are no sensations from the receptors.

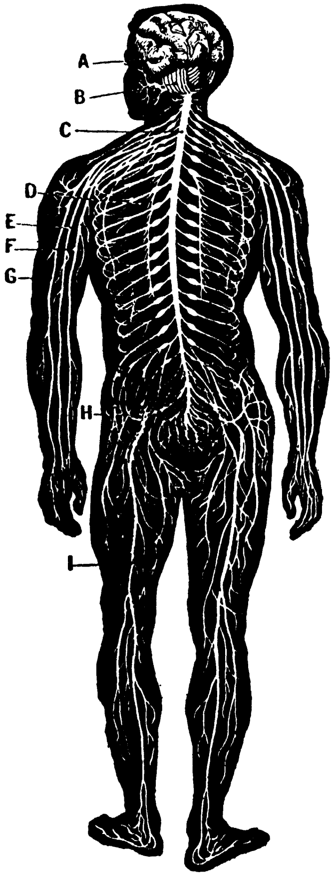


FIG. 56.—Diagram showing the general arrangement of the central nervous system and of some of the nerves. Dorsal view. A. Cerebral hemisphere. B. Cerebellum. C. Spinal cord. D. Nerves of thorax. E, F, G. Nerves of arm. H. Nerves of leg issuing from spinal cord. I. Sciatic nerves of leg.

The spinal cord (Fig. 57) is protected inside the backbone. The central part of the cord is occupied by grey matter which is a tissue consisting largely of nerve cells. The fibres of these, which make contact between the various levels of the cord, con-

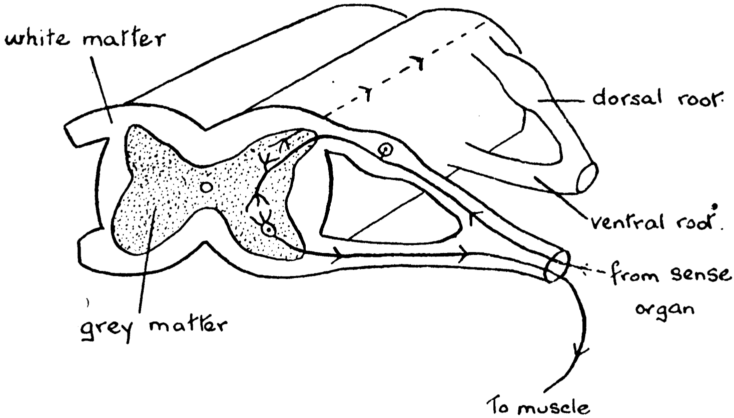


FIG. 57.—Diagram of spinal cord showing the path of impulse concerned in a reflex action.

stitute the white matter in the outer regions of the cord. Each spinal nerve communicates with the cord by two roots; in the dorsal root all the afferent fibres of the spinal nerve pass into the cord; in the ventral root all the efferent fibres pass into the cord.

The spinal cord serves as a means of communication between the brain and the rest of the body. If it is damaged, sensations and actions are very much impaired, and if it is severed there is paralysis and complete lack of sensation in the parts of the body below the cut. Damage to the spinal cord is likely to occur if the back is injured. In addition to its use as a means of communication, the spinal cord itself can initiate a few simple actions as we shall see later.

The brain (Fig. 58) is a continuation of the spinal cord, and consists of the **hind brain, mid brain** and **fore brain.** Much of the brain is hidden by two enormous outgrowths from the fore brain, the **cerebral hemispheres.** The hind brain has a convoluted outgrowth, the **cerebellum,** which is on the dorsal side of the tube-like part, or **medulla,** of the hind brain. In the hind and mid brain the grey and white matter are arranged as in the spinal cord, but, in the cerebral hemispheres, the grey matter is on the surface as the **cerebral cortex.** This consists

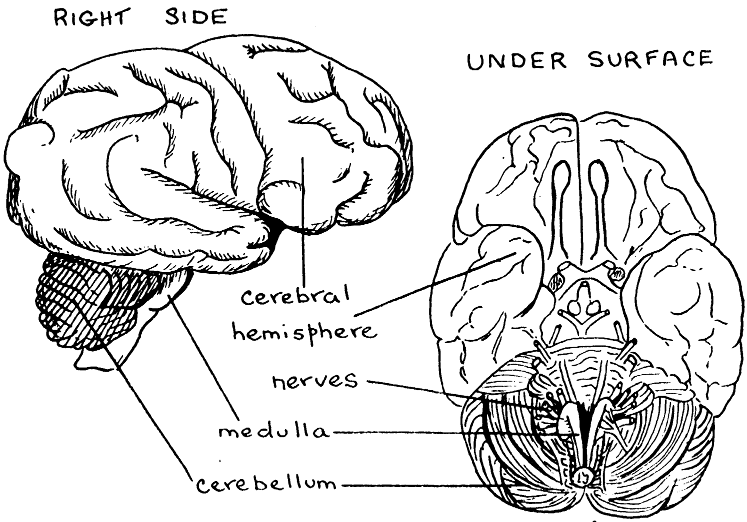


FIG. 58.—Brain of man.

of a very large number of nerve cells with intricate connections both with one another and the lower parts of the nervous system, enabling it to be a most efficient general headquarters of the nervous system. In man's brain, the surface of the hemispheres is much furrowed, and, as the cerebral cortex dips down into each furrow, the total surface area of cortex is enormous, and man's behaviour is very complex. The rabbit's brain has only a few furrows, and hence the behaviour of the rabbit is much simpler than that of man.

ACTIONS

All actions have five stages which may be summarized as (*a*) stimulation of a receptor, (*b*) conduction of afferent impulse, to the central nervous system, (*c*) generation of efferent impulses in the central nervous system, (*d*) conduction of the efferent impulses to the effector, and (*e*) response of the effector (muscle or gland). If you look again at page 135 you will see these stages applied specifically to the action of picking up a piece of paper from the floor.

Now let us consider various kinds of actions, taking as examples rabbit, dog and man as representing three rather different levels of behaviour.

Reflex Actions.—Many actions are common to all three animals. If you prick their legs, the legs will be pulled away even if the animal is asleep; if you make a sudden noise, they jump up and may run away; if you flash a strong light in their eyes they will blink and their pupils will become smaller; if anything irritates their nasal passages, they sneeze; if they smell food when hungry, their salivary glands will secrete. These actions are in the nature of incidents, but others are more continuous. Thus their alimentary canals are contracting and relaxing rhythmically in response to the contact with food, their blood vessels alter their calibre in accordance with the volume of blood circulating, their heart-beats alter in rate in accordance with their speed of movement and their diaphragms and rib muscles are automatically contracting and relaxing and causing breathing. Moreover, there are continual adjustments in the degree of contraction of the various muscles as the posture of the body is changed.

Such automatic actions as the above are called **reflex actions.** In a reflex action, the afferent impulse, on arrival at the central nervous system, always generates the same efferent impulse which causes one particular response. For some reflex actions the efferent impulse is generated in the spinal cord. This is the case in pulling away a limb from a painful stimulus. The afferent impulses travel along afferent fibres, arrive at the spinal cord via the dorsal root of one of the spinal nerves, and are immediately relayed to efferent fibres passing out through the ventral root of the same side. Such a simple reflex requires only two sets of nerve cells and their fibres (neurones) for its performance. The cerebral hemispheres are not required for this action, but, nevertheless, the afferent impulse is relayed by connector neurones up to the cerebral hemisphere so that the animal is conscious of the pain produced by the prick. This consciousness has no influence on the response; in fact, the sensation of pain appears about the same time or even after the limb has already been removed.

Moreover, such an action can take place in a cat or dog whose brain has been removed.

In the foregoing reflex, the efferent impulse was generated in the spinal cord. In other reflexes, the efferent impulses are generated in the brain (blink reflex, pupil reflex, sneeze reflex, salivation reflex). Here again the cerebral hemispheres are not necessary for the action to take place. The pupil reflex is an unconscious one, the animal is unaware of its reaction. The movements of the alimentary canal are regulated by efferent impulses from the medulla. The automatic control of muscular tone is caused by efferent impulses from the cerebellum.

Instinctive Actions.—An instinctive action is one which an animal knows how to do without being taught and the actions considered in the last section are of course instinctive. There are, however, more complex instinctive actions than these simple reflexes. Consider what things a rabbit can do instinctively ; it can make a burrow, seek food, mate with another rabbit and suckle its young. Similarly, a dog has a repertoire of instincts ; it hunts for food, buries its bones, mates, and suckles its young. Each of these instinctive actions consists of a chain of reflexes ; one part of the action sets up new afferent impulses which lead to the next part and so on. Unlike the purely reflex actions, considered in the last section, these instinctive acts of mammals are capable of being considerably modified. Invariably the efferent impulses concerned are generated in the cerebral hemispheres and so the path of the impulse may be varied in accordance with impulses from other parts. Most dogs hunt rabbits instinctively, but a sharp call from the dog's master may put a stop to the hunt.

Man is endowed with an extremely limited repertoire of instinctive actions ; of these, walking, making noises and suckling are the chief ; he has little instinctive action to hunt for food or to make some sort of hole or nest.

Voluntary Actions contrasted with Reflex Actions.—Actions which are not automatic are often distinguished as **voluntary actions.** In the previous parts of this chapter we have referred several times to the action of picking up a piece of paper from

the floor. This is essentially a voluntary action; in it, the response to the particular afferent impulses is by no means predetermined. The efferent impulses are generated in the cerebral cortex and here there is a synthesis of the whole environment so that the particular pattern of response is influenced by other things than the piece of paper on the floor. The man may call somebody else to pick it up for him; he may throw it in the fire or the waste-paper basket, or he may do nothing whatever. Fig. 59 shows the essential difference

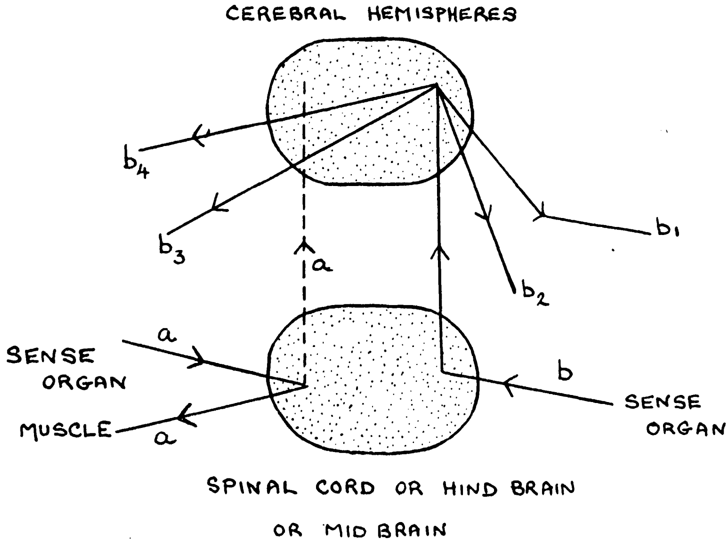


FIG. 59.—Difference between paths of impulses in a reflex action (*a*) and a voluntary action (*b*). There are several alternative responses along paths b_1, b_2, b_3, b_4, which lead to muscles.

between a reflex action (*a*) in which the path of the impulses is predetermined, leading to one response only, and a voluntary action (*b*) in which the path of the impulses in the cerebral cortex is varied, leading to varied responses along the paths b_1 b_2, etc.

Voluntary Actions: (1) Habits.—Now, it is obvious that many voluntary actions can become reflex actions, for, if the same action is repeated many times, the path of the impulse

gradually takes that particular course automatically. Such learned reflex actions are called **habits** to distinguish them from the proper reflexes which do not have to be learned. Dressing yourself was once a complicated series of voluntary actions, but long ago it became a habit, so that you can dress without concentrating on each tiny process. Other acquired habits include riding a bicycle, eating, writing, saying 'good morning', working a typewriter, going upstairs in the dark, and so on.

Habitual actions do not need concentration, and so your mental powers are free to deal with other problems. You will probably realize how much of education consists in the formation of habits. At home and at school you acquire a large range of habits. We can also speak of habits of thought; so soon as the multiplication table became a habit you were at once capable of a fair amount of arithmetic. Learning consists largely in the accumulation of habitual actions or habitual thoughts; once a habit has been acquired another may be built on it and so on.

Dogs and rabbits can also acquire habits. Tame rabbits often run towards one particular member of the household who brings them food. A dog is easily taught a large number of habits, including excreting in the garden and not in the house, begging for tit-bits, running to its master when called, leaping a fence, and so on. Mammal habits are not entirely taught by man. A dog can form the habit of pushing open a gate by lifting the latch, without any help from its master, simply by the method of trial and error. It makes a series of jumps and groping movements and one set of movements produces the desired result. Similarly, rabbits can form habitual actions either by the method of trial and error or by imitation of their fellows.

You will have noticed that man can form many more habits than a rabbit or a dog. This is due partly to man's manual dexterity; he uses his fore limbs to grasp and manipulate his implements, whereas rabbits and dogs still run on all four legs. No dog can be taught to use a screw-driver, manipulate a machine, use needle and thread and material to make garments;

yet man can acquire all these habits. Moreover, rabbits and dogs have no language ; while the use of the written and spoken word has enabled man to accumulate all sorts of complicated habits of behaviour and thought. It is so much easier for the young to learn when their elders can tell them how to do things as well as show them. And you will realize that written language means that the experience of the past is available for the use of the present and coming generations.

Voluntary Actions: (2) Intelligent Actions.—An intelligent action is a successful response to a set of conditions which is new ; it is relatively slow, for in the cerebral cortex the new afferent impulses have to be analysed, as it were, in order to determine the appropriate efferent response. This may be called sizing up the situation.

Suppose a dog has learnt to open a catch on a gate. When it is presented with another gate the latch of which works slightly differently it begins the old method of trial and error until by chance it discovers how to work it. There is no calm consideration and working out of the situation. Of course dogs do show intelligence in some directions. If the gate is locked securely and a gap is cut in the fence a little distance away, the dog may sometimes see the gap and go straight through it instead of having several tries at the gate first. However, in dogs, the power of putting two and two together is severely limited. Apes, on the other hand, are much more intelligent animals and they will do relatively complicated things in response to a new situation. If their food is out of reach and they are given boxes they will consider the situation and then stand the boxes on one another until the requisite height is obtained.

The intelligence of apes is considerable compared with that of dogs, but it cannot compare with the intelligence of man. Even small children are much more capable of sizing up a situation than the most intelligent ape.

As you grow up, you acquire a very large number of habits of action and thought. Take care that your life is not entirely full of these habits so that there is no scope for intelligent acting and thinking. Future human progress depends on our

capacity for intelligent thought and behaviour. We have indeed a rich heritage from the intelligences of the past—the aeroplane, motor-car, printing-press, Beethoven's sonatas, Whistler's pictures, Ely Cathedral, and so on. But do not let us bask in the efforts of the past and become entirely creatures of rote. In this twentieth century we must learn from the past and form habits, but we must also leave our minds free to assess and compare and to make independent judgments. Education is not worth the name if it merely inculcates habits and does not produce the desire to act and think intelligently. Now you will understand why your mathematics teacher does not only set examples which are the exact replicas of those he has shown you but also ones which are sufficiently different to require independent thought on your part. You will also realize why your science teacher always requires you to observe and deduce the inference from a certain experiment instead of telling you the result in advance. And finally you will realize why your literature homework may consist in writing your *own* appreciation and judgment of a certain poem.

CHEMICAL CONTROL OF THE BODY

So far in this chapter, we have attributed all actions to nervous impulses generated in the central nervous system and conducted to the effectors by the peripheral nerves. However, this is not true for every action. Some important responses of the body are brought about by certain chemical stimulants produced by the body itself and transmitted via the blood. Such chemical stimulants are called **hormones.** Sometimes they act directly on the organ concerned and sometimes they act via the nervous system.

You will remember that the rate of breathing is controlled by the proportion of carbon dioxide in the blood. Excess carbon dioxide stimulates the respiratory centre in the brain to generate extra impulses going through the nerves to the diaphragm and the rib muscles. Carbon dioxide is acting as a chemical stimulant.

The secretion of pancreatic juice during digestion is caused by a hormone called secretin which is produced by the mucous

lining of the duodenum. Secretin is conveyed to the pancreas in the blood stream and causes the juice to be poured out. Here action takes place directly and not via any nerve.

The insulin produced by the pancreas itself is another hormone. You will remember that it controls the glycogen $\rightleftarrows$ sugar balance in the body. See Chapter VIII, page 98.

A very important hormone is adrenalin, produced by the outer part of the adrenal glands which are near the kidneys (see Fig. 22). Adrenalin has a very widespread effect on the body ; if it is injected artificially into the bloodstream it speeds up the heart-beat, it constricts the arteries, thus raising the blood pressure and driving more blood into the dilated capillaries of the muscles, and it makes the liver shed much of its stored glycogen so that the sugar content of the blood increases. All these actions result in an increased supply of food and oxygen to the muscles so that they may work more easily than usual. In other words, the individual is braced for an emergency. In extreme conditions we say that the emergency lends wings to our feet, actually it is adrenalin which causes the various effects. In normal life the amount of adrenalin poured into the blood is small but in conditions of stress the supply is increased.

Some hormones have a considerable influence on growth and development. Such a hormone is that produced by the front half of the pituitary gland which is attached to the brain. If the hormone is deficient in youth the child remains small, the sexual organs do not mature and the mentality remains that of a baby. Over activity of the gland, on the other hand, produces excessive physical growth, and in the past men and women seven feet tall owed their gigantism to excessive pituitary activity. Gigantism is less common to-day since an operation can be carried out.

Thyroxin is produced by the thyroid gland lying on each side of the trachea (see Fig. 20). This hormone regulates growth and if it is deficient the child remains undeveloped both mentally and physically. Thyroxin also controls the general chemical activity of the body, and if the thyroxin is excessive the individual is over active, anxious and excitable.

The sexual organs, ovaries and testes (see Chapter XIV, page 175) also produce hormones. These hormones are first produced in adolescence and regulate the development of the secondary sexual characters. In the male the voice deepens and hair develops on the chin. In the female the breasts enlarge and the rhythm of shedding of ova begins.

QUESTIONS

1. (*a*) *Describe the position of the following, and explain the part which they play in vision: iris, lens, retina, ciliary muscles.* (*b*) *Describe the position of the following, and explain the part which they play in hearing: drum, bones of the middle ear, cochlea.*

2. *What do you know of the sense organs of the body other than the eye and the ear? Emphasize the importance of each in enabling the body to function smoothly.*

3. *Give an example of each of the following:* (*a*) *a conscious reflex,* (*b*) *an unconscious reflex. With the aid of a diagram explain fully how EITHER* (*a*) *OR* (*b*) *is brought about. What is the difference between voluntary actions and reflex actions? Explain, with reasons, the category to which habits belong.*

4. *Answer the following:*

(*a*) *What do you know of the structure and uses of the spinal cord?*

(*b*) *Every organ of the body has a nerve supply. Why is this essential? Describe and explain the effect of severing the nerves supplying the arm.*

CHAPTER XII

PLANT RESPONSES

Plants have no muscles, no sense organs and no nervous system. Yet undoubtedly plants respond to the various stimuli which surround them; there is plant behaviour as well as animal behaviour. The directions of growth of root and shoot are not due to chance; they are determined by definite stimuli, so also is the position of leaves in space. It is true that the range of stimuli which seem to be appreciated by plants is more limited than in animals; plants seem insensitive to sound and the majority of them do not respond to contact. Moreover, the responses made by plants to the stimuli which do affect them are not as obvious as animal responses. This is because the most usual response to a stimulus is a growth response, and not a movement response.

RESPONSES OF PLANTS TO LIGHT

Growth responses to Light.—Apart from the part it plays in photosynthesis, light has other important effects on growth. Provided that there is a food supply available in some kind of storage organ, growth will take place in the dark, and in fact the actual rate of elongation in the dark is faster than in the light. It is well known that potatoes and onions kept in the dark often start sprouting; the shoots produced are longer than those developed in the light, they are yellow instead of green, they are weakly and their leaves are ill-developed. Such shoots are said to be **etiolated.** If you are not quite familiar with the difference between etiolated shoots and normal shoots sow two sets of mustard seeds in pots or dishes and keep one set in the light and the other in a dark cupboard. Compare the appearance of the shoots as they develop (Fig. 60). The total amount of growth which can be made in the dark is limited by the food supply available. Since photosynthesis is impossible no more food can be made, and finally you will

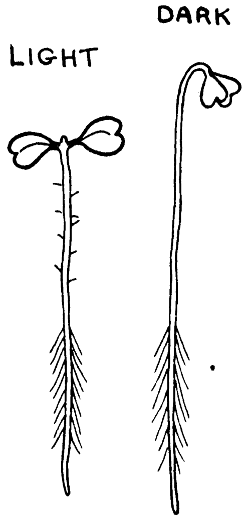


FIG. 60.—Mustard seedlings of the same age.

find that the mustard seedlings in the dark collapse and die. Light as a stimulus causes growth to be slower and sturdier. Apart from its effect on photosynthesis, adequate illumination is essential for the successful growing of crops, for etiolated shoots do not make enough mechanical tissue to support their own weight and consequently they are apt to collapse. With one or two exceptions, such as pea and mustard, light has no effect on the rate and nature of growth in roots; most roots are insensitive to light as a stimulus.

If shoots are illuminated from one side only there will be a retardation of growth on that side while growth continues at the faster dark rate on the shaded side, hence the shoot will grow over towards the light.

Experiment 36.—Sow two sets of mustard seeds in crystallizing dishes. When the shoots are about three-quarters of an inch high put one set inside a box and cut a slit on one side so that light enters from that side only. Leave the other dish of seedlings in full light. By the next day you will see that the shoots inside the box are growing over towards the slit (Fig. 61), whereas the shoots in full light have continued to grow upright. This experiment is best done either out of doors or in the school greenhouse where there is equal light from all sides. If it is done in the laboratory, stand the box and the control set of seeds midway between the various windows. You will find a certain amount of difference in this experiment according as you allow the preliminary growth in the seeds to take place in the dark or in the light. If the shoots have developed in the dark you will find that the growing over to the slit is

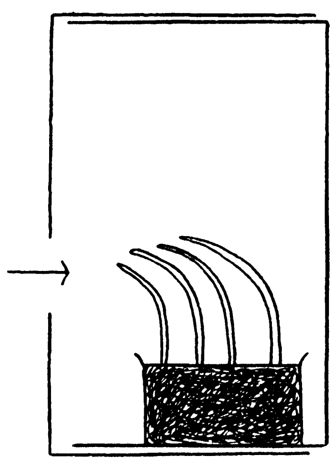


FIG. 61.

much more pronounced than if they have developed in the light. Shoots grown in the light are less sensitive to one-sided illumination.

A growth reaction of a plant whose direction is directly related to the direction of the stimulus is called a **tropism.** **Phototropism** is the term given to the growth responses of plants to light. Shoots grow towards the source of light and are said to be positively phototropic. This reaction is a useful one since light is of such great importance to plants. Under ordinary circumstances it is comparatively rare for a plant to have darkness on one side and light on the other, but it often happens that a plant has better illumination on one side than on the other. If you have ever tried to grow a pot of daffodils by a window you will know that they grow over towards the window side and that all the flowers have their trumpets turned to the window. If you want symmetrical development of the daffodils you must turn round the bowl at regular intervals so that first one side is exposed to the window and then the other.

The position of leaves is largely determined by the stimulus of light ; the flat surface of the leaf is usually placed so that the light falls on it at right angles. If you examine the leafy shoots of a hedge (privet, elm, hawthorn) you will find that at the top of the hedge, where the chief incident light is vertical, the planes of the leaves are horizontal, while at the side of the hedge, where the main incident light is horizontal, the planes of the leaves are vertical. The growth responses of leaves are largely responsible for the leaf mosaic of a tree ; the arrangement of leaves at right angles to the incident light means that they are able to absorb the maximum amount of light energy for photosynthesis.

It is possible for you to find out more about how plants respond to light by a modification of the last experiment.

Experiment 37.—Set up a dish of millet or wheat seedlings in a box with a hole in one side as in the last experiment, but cover the tops of some of the shoots with minute tin-foil caps. These tips will be screened from the incident light by the tin-foil, whereas the tips of the uncovered seedlings are exposed to light. You will find that whereas the uncovered seedlings grow across towards the slit the covered shoots

remain upright. The actual region of bending in the uncovered shoots is below the tip. In the covered seedlings the actual region of greatest growth is not under the tin-foil cap; the region where the growth response would occur is exposed to light and yet the covering of the tips prevents the response from taking place.

It seems that the tip is the perceptive region for light; it almost plays the part of a receptor in an animal. The elongating region below plays the part of the effector. With its tip in darkness a shoot cannot respond to light any more than a blind man will pick up a piece of paper. The man has the power of picking up the paper because his leg and arm muscles are capable of working but he does not see it. Similarly, the covered shoot has the power of responding to light because its elongating region is intact but with its tip covered the stimulus, light, is not felt.

Other responses to Light.—Growth responses are lasting because they are due to permanent cell changes. In a few plants light and darkness cause temporary and localized changes in cell turgor resulting in temporary movements. Such are the so-called 'sleep movements' of various flowers and leaves. As a rule, there is folding up of the structures in question at night and expansion in the day-time. This is the case with clover leaves (Fig. 62) and with daisy flower heads. Some flowers, such as those of the evening primrose, close in the light and open in the dusk. Many of the so-called sleep movements are influenced considerably by temperature.

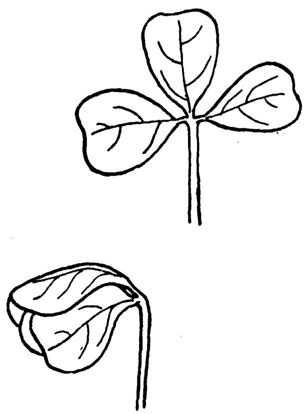


FIG. 62.—Sleep movement of a clover leaf.

RESPONSES OF PLANTS TO GRAVITY

When you are planting seeds it is comparatively seldom that you take the trouble to place each one separately in a particular position in the soil. Indeed, with such small seeds

as those of turnip and onion it would be very difficult to set each seed separately. Nevertheless, however the seed is sown, upright, upside down or sideways, the main root will always grow downwards and the main shoot upwards. It is possible to show this orientation of growth by a simple experiment.

Experiment 38.—Put several broad beans to germinate and when the roots are about ¾ inch long set two of the seeds in a jar as shown in Fig. 63. On the under side of the cork is wet cotton wool and filter paper. Put the jar in a dark cupboard. After a day or two you will see that the horizontal root has started to grow downwards by making a growth curvature, while the root, which was upright at the beginning, has continued to grow in the same vertical direction. If shoots have appeared by the end of the experiment, you will see that the shoot from the horizontally placed seed starts to grow up vertically.

Now repeat the experiment but decapitate the roots. This time there is no response on the part of the horizontal root, since the region of perception has been removed.

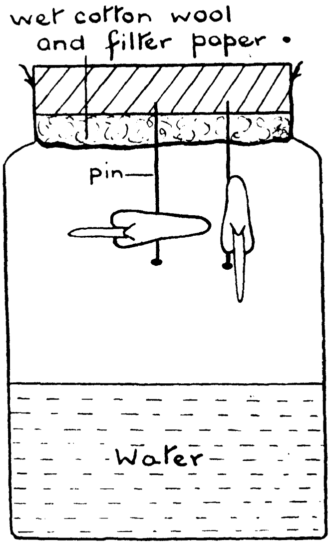


FIG. 63.

The stimulus responsible for roots growing downwards and shoots growing upwards is not light, for the experiment was carried out in the dark. Also, seeds are planted under the soil where no light can reach them, and yet roots grow down and shoots grow up. The stimulus which causes the directive growth is the force of gravity. When a seedling is in a horizontal position the side of the root towards the earth grows more slowly than the side away from the earth and hence the root makes a downward growth curvature. In the shoot the side towards the earth grows faster than the side away from the earth and hence the shoot makes an upward growth curvature.

It is difficult to prove that gravity is the actual stimulus, for it is, of course, quite impossible to eliminate gravity.

However, it is possible to arrange for seedlings to be rotated so that first one side and then the other is towards the earth. An instrument on which seedlings can be rotated is called a **klinostat.** It has a clockwork mechanism and carries an axle on which a large cork is rotated. There is a large mica cover which can be fastened on to the cork when necessary.

Experiment 39.—Set some mustard seeds or wheat grains to germinate in 2 small crystallizing dishes. When the shoots are ½ in. long fasten one dish to the cork of the klinostat by means of plasticine so that the shoots project horizontally. Put the other dish as a control on the bench so that the shoots are in a horizontal position. In the course of the next 24 hours you will see that the shoots on the klinostat continue

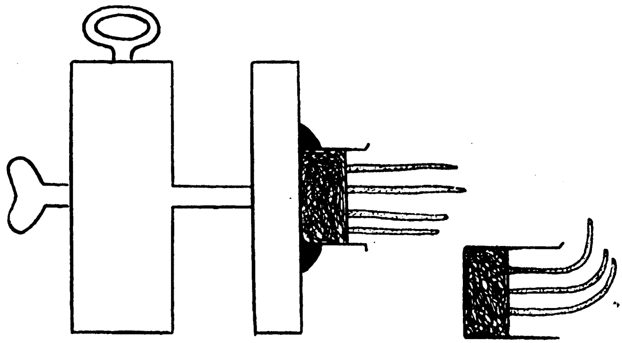


FIG. 64.

to grow out horizontally whereas the shoots which were not rotated have grown through a right angle (Fig. 64). In the rotating shoots first one side was towards the earth and grew faster, but half an hour later the opposite side was towards the earth and grew faster. Hence the net growth was equal on all sides and the shoots grew horizontally. The experiment can be carried out in light or darkness.

The klinostat can also be used to investigate the growth of roots. Use pea or bean seedlings with roots about ½ in. long. Fasten them with pins tc the cork of the klinostat so that the roots project horizontally. Line the mica cover of the klinostat with wet blotting paper and put it in position. As the klinostat rotates, the roots continue to grow horizontally.

The growth responses of roots and shoots to gravity are

called **geotropisms.** Main roots are positively geotropic and main shoots are negatively geotropic. Side roots and shoots set themselves at a definite angle with the vertical. Geotropism of roots and shoots accounts for the constant orientation of plant organs ; it is responsible for the downward growth of roots and the upward growth of shoots. You will notice that shoots are sensitive both to light and gravity. As a rule these stimuli work together and the upward growth away from the direction of gravity coincides with upward growth towards light. Plants growing under a hedge or in a room near a window are subjected to stimuli acting in different directions ; the stimulus of gravity always acts in a vertical direction but the stimulus of light acts horizontally. The shoots of these plants usually show a growth curvature towards the incident light. Light is a more powerful stimulus than gravity.

OTHER STIMULI AFFECTING PLANTS

The direction of growth of roots is due to the stimulus of gravity and also to the stimulus of water. **Hydrotropism** is the growth response to water. Under normal circumstances the positive hydrotropism of roots simply reinforces the effect of their positive geotropism. It is possible to fit up an artificial arrangement in which gravity and water act in opposite directions on roots.

Experiment 40.—Set mustard seeds in a thin layer of damp sawdust on a piece of perforated zinc or wire gauze to act as a sieve. The wire gauze must not have an asbestos centre. Put the perforated zinc on a bowl containing water and cover the sawdust with an evaporating dish to prevent excessive evaporation (Fig. 65). As the seeds germinate the roots grow through the holes. When the roots have appeared through the holes, put the sieve on

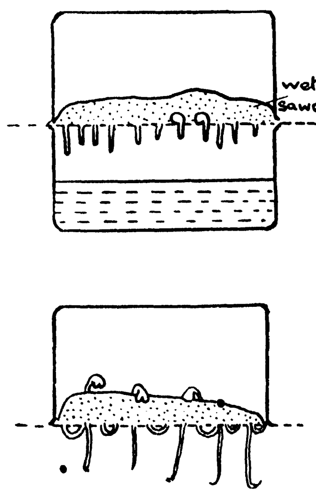


FIG. 65.

the ring of a retort stand and raise it a few inches above the bowl. At the same time water the sawdust thoroughly. Now the nearest source of water for the roots is above them in the sawdust. You will find that many of the roots grow in a loop-like fashion back into the sawdust; they are in fact growing upwards in spite of gravity.

Root growth is also determined by the air of the soil acting as a stimulus. In well-aerated soils this reaction is of comparatively little significance, but it is often very prominent in pot plants. When re-potting plants you have probably noticed how the roots mass themselves on the periphery of the soil just within the pot. This massing of roots is due to their growth towards the air which enters through the pores of the pot. Such a plant is said to be pot-bound and insufficient air supply is one of the chief disadvantages of growing plants in pots.

There are other stimuli to which a few plants respond. Some flowers, such as crocus, open and shut in accordance with temperature. The tendrils of climbing plants are sensitive to contact so that they form corkscrew curves and start to grow round a support. Some of you may be familiar with the sensitive plant Mimosa, whose leaves fold up and droop as a result of pinching them; afterwards recovery takes place.

QUESTIONS

1. *Describe ONE experiment (with a control) to demonstrate each of the following statements:*

(*a*) *The main root of a plant is positively geotropic.*

(*b*) *The tip of the shoot perceives the stimulus of light.*

(*c*) *If gravity and light act in different directions on the shoot of a plant the response of the shoot is to light.*

2. *What do you know of the effect of light on the following in plants: (a) rate of growth, (b) food manufacture, (c) position of the stems and leaves in space, (d) movements of leaves and flowers? (See also Chapter VII.)*

CHAPTER XIII

REPRODUCTION IN PLANTS

Neither flowering plants nor mammals are immortal; they have a limited length of life and the race is then carried on by the offspring which they have produced in their lifetime. In many animals and plants the number of offspring produced per year far exceeds the deaths of the older generation. Now, since the world is already fully populated by animals and plants, there is not room for all the new arrivals and so a large proportion of the new generation are not able to survive. On the whole, reproduction is a wasteful business. Only in the white races of humans do the deaths per year tend to exceed births. Let us enquire into the process of reproduction more closely.

REPRODUCTION IN THE BUTTERCUP AND TULIP

Structure of the Flower.—Flowering plants reproduce by seeds, and seeds are preceded by flowers, which play an essential part in reproduction. A buttercup (Fig. 66) has a simple type of flower which can be regarded as a sort of telescoped shoot bearing specially modified floral leaves. The outermost of these are five green and leaf-like structures which protect the flower in bud; they are called **sepals** and, in one of the commonest varieties of buttercup, they become reflexed when the flower opens. Next come five yellow shiny **petals,** each with a small flap at its base making a little pocket structure within which a sugary fluid, **nectar,** is secreted. This structure is called the **nectary.** Both sepals and petals are attached to the top of the flower stalk or **receptacle** which projects like a cone into the flower. Above the petals the receptacle bears numerous **stamens**, each consisting of a stalk-like **filament** and a head called the **anther.** The anther has four narrow lobes containing pollen; these are the pollen sacs, and they burst when they are ripe and set free **pollen** as a yellow **powder.**

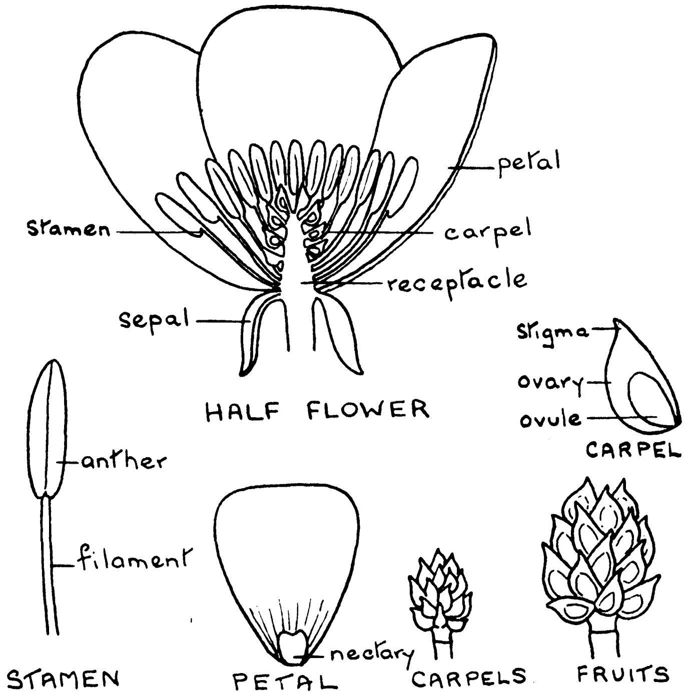


FIG. 66.—Buttercup flower.

The top of the receptacle is covered by numerous **carpels** each containing a single **ovule.** The top of the carpel has a projecting beak, the **stigma**, and the lower part of the carpel containing the ovule is called the **ovary.**

The tulip flower (Fig. 67) does not show any distinction between sepals and petals ; it has six brightly coloured floral leaves called **perianth leaves** which are arranged in an outer whorl of three and an inner whorl of three. It has six stamens in two whorls of three, and in many tulips both the anthers and the pollen are purplish brown instead of yellow. The centre of the tulip flower is occupied by a three-sided ovary made of three carpels joined together. Internally the ovary is divided into three chambers, and the ovules form a row down the inner edge of each chamber. The ovary is sur-

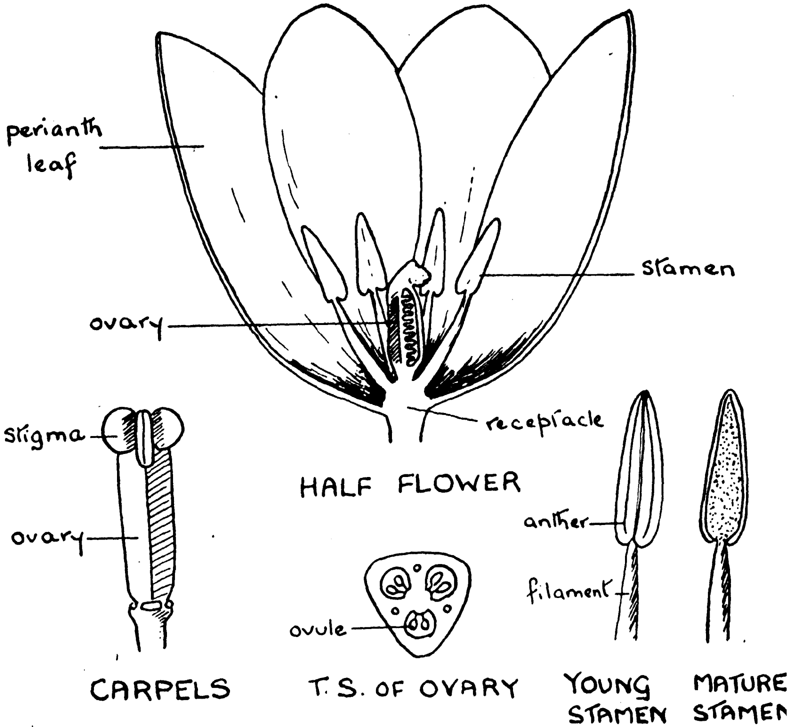


FIG. 67.—Tulip flower.

mounted by a three-lobed stigma. There is no nectar in the tulip.

Pollination.—The seeds are developed from the ovules and the seed pod or fruit is formed from the ovary. This development cannot take place without the help of pollen which plays an essential part in promoting development. The first stage in the process is the transference of pollen grains from the stamens on to the stigma; this is called **pollination.** If the pollen comes from stamens of the same flower as the stigma the process is called **self-pollination**; in **cross-pollination** the pollen comes from the stamens of a different flower. Either cross-pollination or self-pollination may be brought about by the wind blowing the dusty pollen about. Pollination is also caused by insects. Bees visit both tulips and buttercups

to collect pollen ; from buttercups thay also collect nectar. As the insect alights on the flower its hairy under surface becomes dusted with pollen and some of this is easily rubbed off on to the stigmas of that flower or of the next flower visited by the bee. You must realize that the bee is an unconscious agent in causing pollination ; it visits the flowers for its own purposes of food gathering, and the brushing of pollen on to the stigma is purely incidental so far as the bee is concerned. Bees are not the only visitors to flowers ; others, such as butterflies, moths and male gnats collect nectar, while hover-flies collect both pollen and nectar. The smaller insects may collect the pollen and nectar without going anywhere near the stigma and hence they do not cause pollination.

You can show that pollination is an essential prelude to fruit and seed formation by an experiment with tulips.

Experiment 41.—About 30 growing tulips are necessary for this experiment. When the flowers are still in bud, force apart the green perianth leaves and remove all six stamens from 20 of the flowers. These stamens must not have shed their pollen, otherwise the experiment is useless. Cover up the flowers with bags made of muslin or net with draw threads of wool, but be careful not to draw the wool too tightly round the flower stalk. The bags prevent insects from visiting the flowers. In the course of the next week or ten days the flowers open and the perianth leaves become coloured ; stamens are now fully developed in the uncovered flowers. Remove the bags from ten of the covered flowers ; deliberately pollinate the stigmas by rubbing mature stamens over them and then replace the bags. Now you have 20 covered flowers of which 10 have been pollinated and 10 have not been pollinated ; the bags effectively prevent accidental pollination. Tie up the plants to stakes and put tape round the stakes of those which have been pollinated. Look

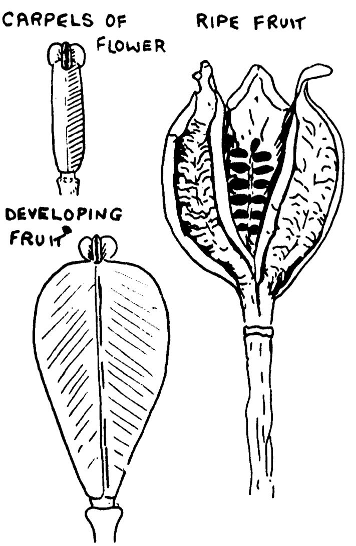


FIG. 68.—Development of the tulip fruit.

after the plants in the succeeding weeks and, in particular, water them if it is dry. After four weeks remove the bags and you will see that nearly all the plants which were pollinated have swollen green pods developing from the ovaries (see Fig. 68), while in the unpollinated plants the ovaries have shrivelled without any further development. Very occasionally you may find that one of the unpollinated flowers has a developing pod; this is because stray pollen grains have been blown through the net bag; it is unlikely to occur. More often you will find that one or more of the pollinated plants fails to develop a pod. This means that pollination is not everything; other essential happenings must follow and, if these fail, no fruit is formed. You are recommended to do this experiment with a large number of tulips, 10 pollinated and 10 unpollinated, but it can be done with less. Six of each kind is a minimum, with two or three extra flowers from which stamens can be used.

Fertilization.—Pollen grains can germinate if they are supplied with the necessary food. Scatter pollen from a bluebell into 5 per cent. sugar solution and keep the suspension for two or three days. Then examine a drop of the suspension under the microscope and you will see that many of the grains have grown into delicate protoplasmic tubes (Fig. 69).

This germination of pollen grains takes place on the stigma and the tubes penetrate into the solid tissue below and dissolve food for themselves by the action of enzymes. Finally, the tubes reach the cavity of the ovary, and here there seems to be a definite attraction between the tube and the ovule, so that the tube grows right into the ovule (Fig. 69), where a union takes place between two nuclei. One of these nuclei belongs to the pollen tube and is called the **male gamete.** The other nucleus was produced by the ovule and is called the **female gamete.** The process of union between male and female gamete is called **fertilization** and the product of union is called the **zygote.** The buttercup has only one ovule per ovary and, although several pollen tubes may start growing from the stigma, only one is successful in causing fertilization. In the tulip many pollen tubes cause fertilization for there are many ovules. In all ovules there is also a subsidiary fertilization in addition to the main fertilization. In this subsidiary fertilization another pollen nucleus unites with two other ovule nuclei.

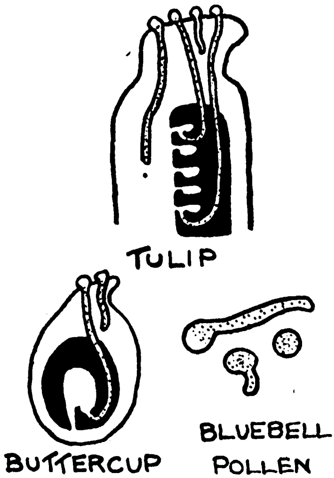


FIG. 69.—Fertilization.

Fertilization of buttercup ovules can only be caused by buttercup pollen ; if pollen from another flower alights on the stigma it is unable to penetrate into the tissues. Similarly, tulips cannot be fertilized by buttercup pollen.

Development of fruit and seeds.—The union of male and female gametes in fertilization seems to act as a stimulus causing considerable changes in the ovaries and ovules, while the other parts of the flower gradually wither away. In the experiment with the tulips you noticed the developing green fruits formed from the ovaries (Fig. 68). Developing buttercup fruits are easy to see on the plants themselves forming green clusters on the receptacles (Fig. 66). Later on both tulip and buttercup fruits become dry, hard and brown. All this development necessitates food which is supplied from the leaves of the parent. The preliminary stages of fruit formation are critical ones for the plant, and unfavourable external conditions, such as drought or frost, may kill the young fruits. Fruit growers always regard the period immediately following flowering as a critical one ; a late frost may ruin the plum and cherry crops for the year.

Meanwhile, the ovule has also been enlarging and developing. Its wall has become the hard seed coat. The zygote has formed a young plant or **embryo**, using food supplied by the parent. This food is stored up in a tissue called the endosperm formed from the product of subsidiary fertilization. The embryo consists of young root or **radicle**, young shoot or **plumule**, with either one or two specialized leaves or **cotyledons.** The tulip has one cotyledon, the buttercup has two. The embryo gradually encroaches on the endosperm, but in both tulip and

buttercup some of the endosperm is left by the time the seed is ripe. In other seeds, such as bean, pea, oak, the endosperm is completely used up by the time the seed is ripe, but some of the food store has been transferred to the embryo itself where it is stored in the cotyledons (see Fig. 84).

When seeds and fruits are ripe they are detached from the parent. Buttercup fruits are relatively light and are easily blown about by wind; each fruit contains a single ripe seed. Tulip fruits open when they are ripe (Fig. 68) so that the seeds are exposed and it is the seeds themselves which are blown about by wind.

Seed production as an example of sexual reproduction.—We have seen that seed production necessitates a preliminary process of fertilization, which is a union of gametes. This type of reproduction is called **sexual reproduction.** It seems a contradiction in terms that many progeny should be produced by a process of union; it would seem that fertilization should halve the existing numbers, not multiply them. That the final effect is one of multiplication and not of reduction is due to the fact that one plant has many ovules, and when each of these is fertilized it can form a seed. Thus, a single tulip fruit contains many seeds, and although a single buttercup fruit contains only one seed, each buttercup flower can produce 20 fruits, and a single buttercup plant can have six flowers, making a total of 120 seeds per plant.

OTHER FLOWERS, WITH SPECIAL REFERENCE TO POLLINATION

Knowledge of tulip and buttercup should be a guide to you when you come to study other flowers, in much the same way as knowledge of two relatively simple piano studies are a guide to more complex studies.

Pollination by Insects.—Some of the more complex flowers show interesting methods of pollination. In antirrhinum (Fig. 70) the petals form a closed structure which can be opened only by a force pushing on the lower lip. A bee has a heavy body, and when it lands on the lower lip it forces the flower open and crawls into the tube in search of the nectar, which

is at the base of the tube. Its upper surface becomes dusted with pollen from the stamens and when it goes to another flower, some of the pollen will get rubbed on to the stigma. It is unlikely that the flower is self-pollinated, because the stamens ripen before the stigma.

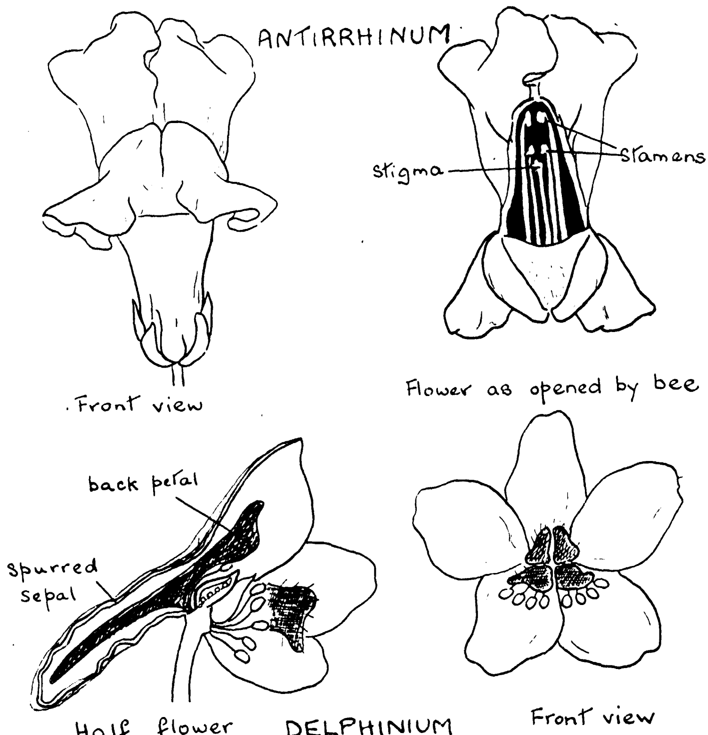


FIG. 70.

The delphinium flower (Fig. 70) has showy sepals, one of which is prolonged into a spur. Within the spur are two horn-shaped back petals containing nectar. From the front of the flower this nectar can only be obtained by a long-tongued insect, and its under surface will be in contact with the stamens and stigmas. As in the antirrhinum, stamens ripen before the stigmas, and hence self-pollination is unlikely.

You must not think that all showy rather complex flowers are necessarily pollinated by insects. The ordinary garden pea nearly always pollinates itself, although, in other flowers of the same family, such as lupin, insect pollination takes place.

Wind-pollination.—Some flowers are inconspicuous because sepals and petals are either absent or very poorly developed. Grass flowers (Fig. 71) are encased in bracts, and each flower

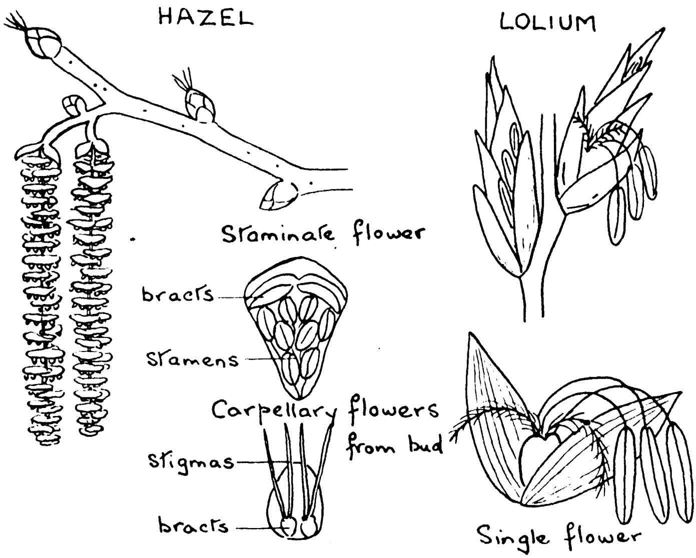


FIG. 71.—Flowers of hazel and lolium (a grass).

has three stamens and an ovary surmounted by two feathery stigmas. Grasses are pollinated by wind; the stamens have long thin filaments which cause them to sway in the slightest breeze, while the feathery stigmas are very suitable for catching some of the wind-borne pollen.

In many common trees (oak, beech, hazel, poplar, birch) there are two kinds of flowers, one containing stamens and no carpels, and the other containing carpels and no stamens (see Fig. 71 showing hazel). The staminate flowers are often arranged in long pendulous catkins which sway in the breeze

and set free clouds of pollen. Usually, flowering of these trees takes place either before the leaves appear or when the leaves are still young and small. If the tree were in full leaf there would be little chance of the pollen reaching the stigmas for the leaves would act as barriers.

Wind-pollination is much more wasteful than insect-pollination. However, all wind-pollinated plants produce vast clouds of pollen.

KINDS OF FRUITS

Fertilization is fairly similar in all flowers, but there is considerable variation from one plant to another in the kind of fruit produced. When ripe, a fruit may be dry and hard or juicy and soft.

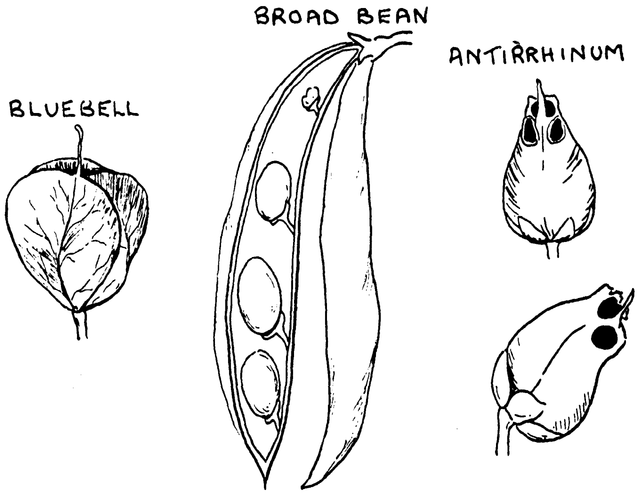


FIG. 72.—Dehiscent fruits.

Dry fruits may be like the tulip and open when they are ripe; they are said to be **dehiscent.** Some dehiscent fruits showing their methods of opening are shown in Fig. 72. Other dry fruits are like the buttercup and never set free their seeds; they are said to be **indehiscent.** Indehiscent fruits are very common indeed, and some of them are shown in Fig. 73.

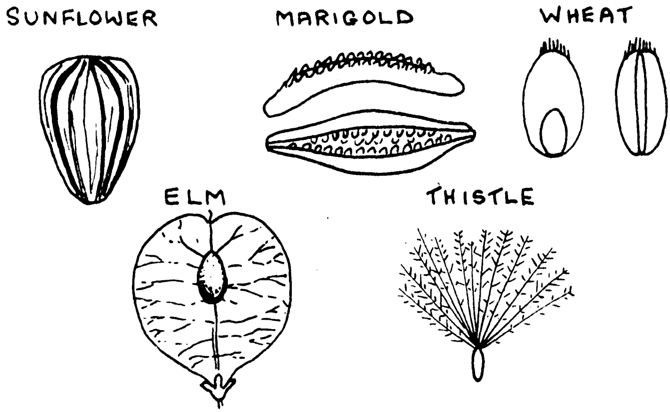


FIG. 73.—Indehiscent fruits.

In some juicy fruits the whole of the fruit wall becomes juicy; these are called berries, and the tomato and gooseberry are shown in Fig. 74. In plums and allied fruits the inner part of the fruit wall becomes hard; such fruits are called drupes. Blackberries and allied fruits have clusters of drupes.

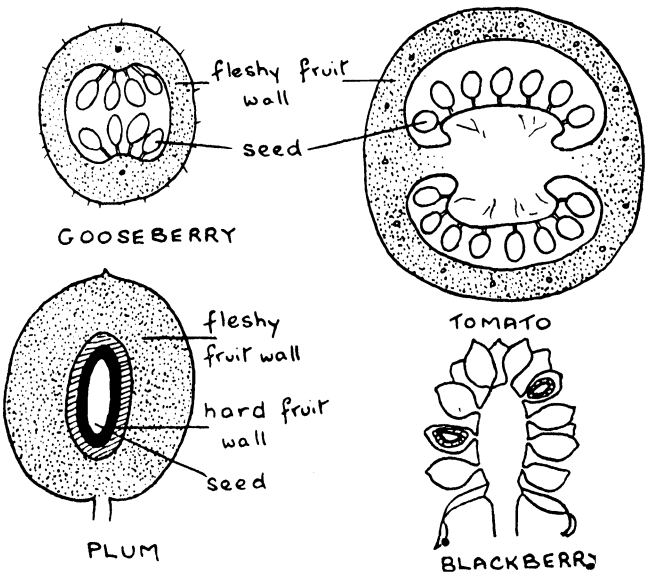


FIG. 74.—Juicy fruits.

Sometimes the effects of fertilization extend to the receptacle which becomes juicy. This happens particularly in the rose family, and Fig. 75 shows how strawberry, hip and apple are developed from the receptacle.

DISPERSAL OF FRUITS AND SEEDS

All plants produce a larger number of seeds than will be able to survive. If these seeds drop in large numbers immediately below the parent then, even if the place is not already occupied and growth takes place, there will be very severe competition between the young plants themselves and between the young plants and the parent. There is competition in the soil for root space and for mineral salts. The shoot systems compete for light and, if the parent plant happens to be a tree, the seedlings have very little chance of survival. The severe competition caused by overcrowding means that none of the young plants can attain full vigour. You will be familiar with the evil effects of overcrowding from the appearance of a row of radishes or lettuces which have not been thinned. Thinning of seedlings is one of the most important gardening operations.

If seeds are dispersed far and wide from the parent there is a greater chance that some of them at least will have a chance of developing into vigorous plants. Of course, dispersal is full of hazards, for some of the seeds will land in places even more unfavourable than under the parent, such as tarred roads or fields already fully occupied by grass, but a few will reach sparsely populated places where development is possible.

Wind is the main agent of dispersal. Antirrhinum and poppy fruits open by pores when they are ripe, and as the plant sways in the wind the minute seeds drop out through the pores and are then taken up by the wind and scattered (Figs. 72 and 76). Willow herb has fruits which open and set free small seeds with tufts of hairs (Fig. 76). Many indehiscent fruits, such as dandelion, thistle, clematis, have hairy attachments which act as parachutes and enable the fruits to be carried away by the wind (Figs. 73 and 76). Other indehiscent fruits, such as ash, sycamore, elm, have wing-like outgrowths on the

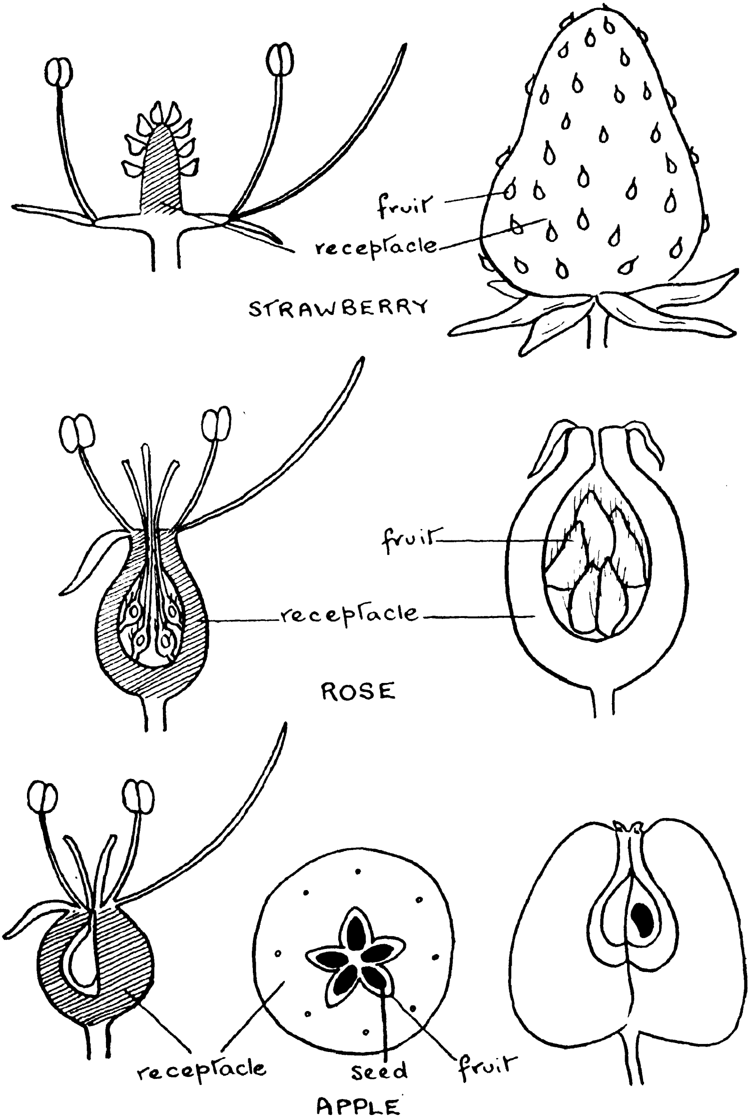


FIG. 75.—Fruits with developed receptacle.

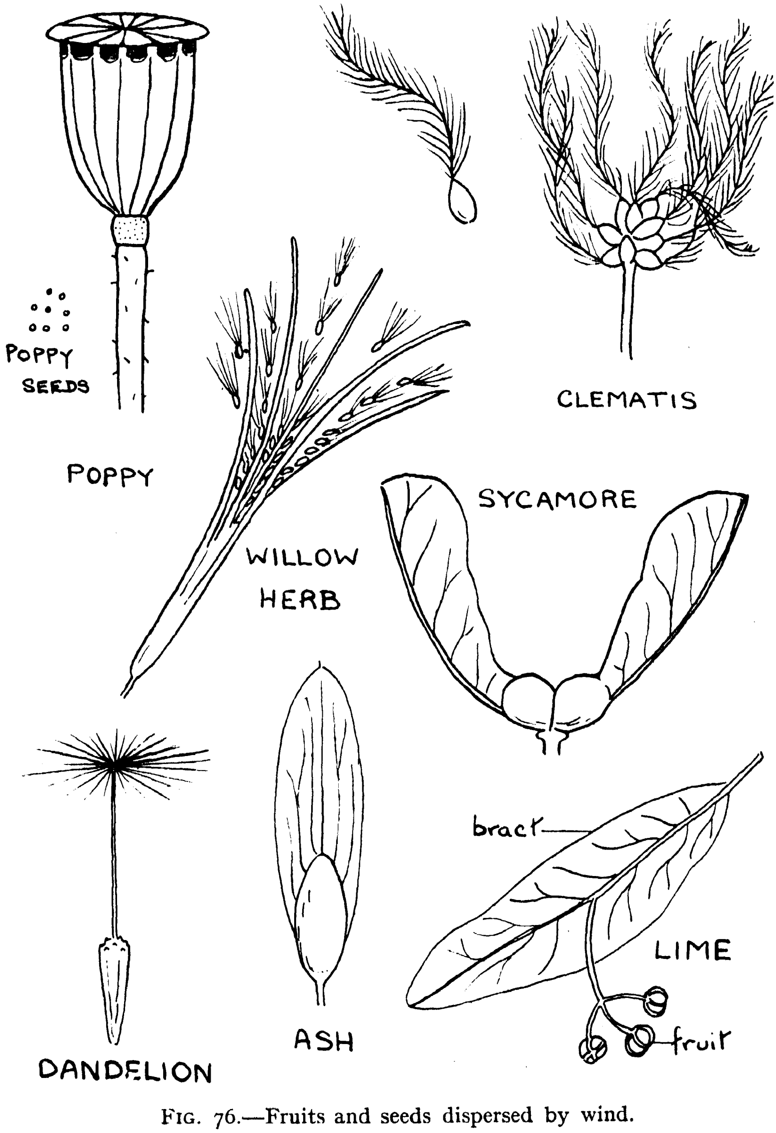


FIG. 76.—Fruits and seeds dispersed by wind.

fruit wall which catch in the wind and aid dispersal (Figs. 73 and 76). In the lime a wing is formed by a specially modified leaf (or bract) underneath the group of fruits (Fig. 76). The bombed sites in some of the large towns presented empty spaces for the colonization of plants. It is true that the 'soil' available was chiefly debris dust with very little humus so that the situation was not particularly favourable. The plants which developed on such bombed sites were usually those which could have reached the place by wind dispersal: willow herb and coltsfoot were common.

Animals help to disperse fruits and seeds. Small seeds are

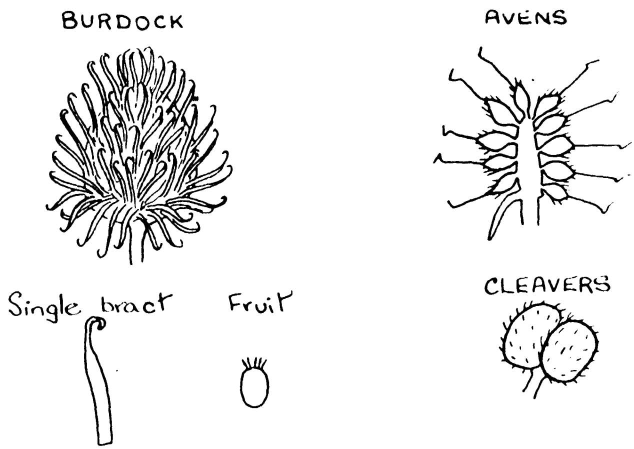


FIG. 77.—Fruits dispersed on the fur of animals.

sometimes carried long distances between the toes of birds. Hooked fruits, such as burdock, avens and cleavers, catch in the fur of sheep or rabbits or in the clothing of humans (Fig. 77). By the time the animal rids itself of the clinging fruits, it may have gone some distance.

Juicy fruits are eaten by animals, especially by birds. If the seeds (or in drupes the hard parts containing the seeds) are small, they are swallowed with the juicy part but they are not digested. Hence they are passed out of the animal's body unharmed with the undigested residue. The undigested residue is likely to be ejected at some considerable distance

from the place where the fruit was eaten. Fruits whose seeds are dispersed in this way are bryony, blackberry, gooseberry. Humans pass out seeds in their faeces (tomatoes, strawberry, gooseberry), but in this case there is little chance of the plant being able to grow, since the majority of human sewage is ultimately cast into the sea.

In some juicy fruits the seeds (or the parts containing the seeds) are much too large for animals to swallow, and so the animal ejects them from its mouth, and only swallows the juicy part. Such is the case in rose hips, plums, cherries, oranges, apples. Here there is less chance of dispersal since the animal is likely to eject the hard parts on the spot. It is true that birds sometimes carry away whole cherries, but more frequently they peck away all the juicy part of the fruit and leave the stone hanging.

A few fruits disperse their own seeds by an explosive mechanism. Gorse pods open with some violence and may jerk out their seeds for a yard or two. Obviously, this is a relatively ineffective method and does not ensure wide dispersal. You must not think that all plants disperse their seeds far and wide. Some plants do not disperse their seeds at all. Horse chestnuts have dehiscent fruits but the large brown seeds drop straight down; seeds of peas and beans and fruits of oak also drop beneath the parent. Large seeds are at a disadvantage in dispersal, but, on the other hand, they contain exceptionally large food stores which give the young plant a good start.

VEGETATIVE REPRODUCTION

Many plants have another way of reproducing themselves other than by seeds. If you wish to grow a potato crop you do not plant potato seeds, you plant tubers. A tuber is not preceded by a flower, it is a vegetative part of the plant which becomes detached from the rest and is able to grow independently. The potato is a cultivated plant and the tubers are usually dug up by man and deliberately planted. In its wild state the tubers would be left in the soil and would develop in the following season. Such reproduction, which is not

preceded by flowers and involves no sexual process, is called vegetative reproduction.

In Chapter I we mentioned other plants which reproduced vegetatively, such as the strawberry, mint, tulip and crocus. For details read again pages 7 to 9 and study the drawings.

In the natural state, vegetative reproduction does not allow much dispersal of the plant; even the longest strawberry runners reach very limited distances from the parent. On the other hand, in its early development the young strawberry is attached to the parent and can obtain food from it. In other words, in vegetative reproduction the offspring is well nourished but the chance of dispersal is very limited.

Gardeners make great use of vegetative reproduction. In Chapter I we described how perennial plants are divided and separated. This is a quick way of propagating plants, for the transplant is fairly well developed. Growth of plants from seeds takes longer and is more hazardous. On the other hand, if the gardener is interested in breeding new varieties he must grow seeds instead of propagating vegetatively. The tuber of a potato plant will grow into plants similar to the parent, but seeds of a potato plant may sometimes produce new varieties.

Gardeners can use artificial methods of vegetative reproduction for propagating. In Experiment 3 (page 36) we described how to take a cutting. It is not a natural process for a shoot to fragment itself, but many plants have the power of producing roots from the cut end of a shoot (e.g., mint, pansy, geranium). Root formation is aided if the cutting is planted in sand. Many gardeners make pockets in the soil and fill the pockets with sand. Then a cutting is planted in each pocket. On page 51 we discussed the advisability of shielding cuttings from the hot sun. Root formation by cuttings may also be stimulated by growth-promoting chemicals called hormones (see Chapter XV, page 190). Many shrubs and trees can be propagated by cuttings; such are gooseberry, currant, willow, poplar.

In propagation of fruit trees and roses grafting is used. A shoot of the desired variety with a pointed end (the scion) is

inserted into the V-shaped cut surface of a common variety (the stock). The stock is of course rooted. The scion and stock are firmly bound together and gradually the tissues of scion and stock become continuous so that the scion continues to develop on the main trunk and roots of the stock. If the only means of growing a new variety was from apple pips there would be little chance of obtaining a crop of new apple fruit for many years. Grafting gives us a short cut for introducing new varieties of fruits and roses into common cultivation. In successful grafts the stock provides roots and main stem, and all further development concerns the scion. Occasionally resting buds left on the stock start to develop and you may be familiar with briar shoots which sometimes develop from the stock of a rose. Obviously, these briar shoots must be removed.

Budding is another method of propagating roses and fruit trees used by gardeners. A bud of the desired variety is removed together with a shield-shaped layer of stem. This shield is inserted into an incision made in the side of the stock and both are bound firmly together. As in grafting, the tissues of the shield and stock grow together and the bud develops on the stock.

REPRODUCTION IN FERNS

Ferns do not have flowers ; they reproduce by means of minute brown **spores.** These are formed in very large numbers in specialized structures on the backs of the leaves. There is no space in this book to give details of the structures which contain the spores. Suffice it to say that a single fern plant discharges many thousands of dust-like spores of much the same size as pollen grains.

A fern spore does not grow directly into a new fern plant. Under favourably damp conditions it grows into a thin, flat green structure called a prothallus (Fig. 78). This is seldom as much as ½ inch long and anchors itself to the soil by outgrowths rather like root hairs called rhizoids. On the prothallus are formed the organs of sexual reproduction. Round the edge of the prothallus are formed some spherical structures

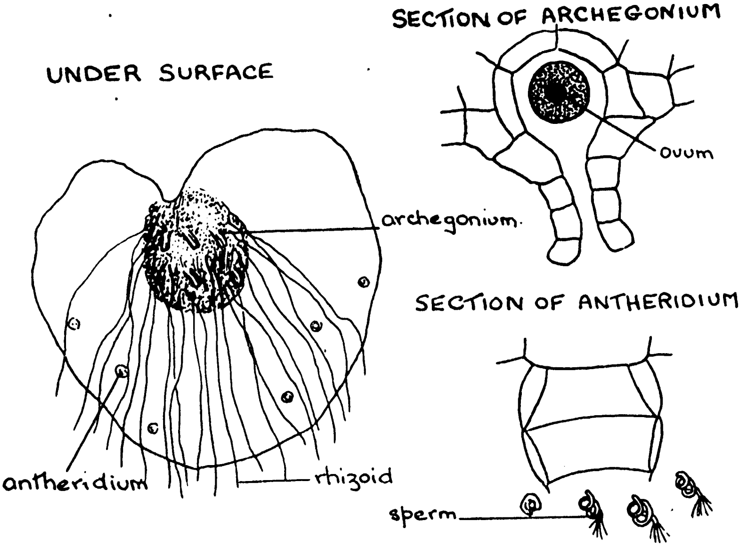


FIG. 78.—Fern prothallus.

called antheridia containing a large number of male gametes or **sperms.** When the antheridia burst the sperms swim out by means of minute protoplasmic lashes or cilia. In the centre of the prothallus are formed some flash-shaped structures called archegonia. In each archegonium a single female gemete or **ovum** is produced. The ovum is stationary and the sperms seem to be attracted to it and swim down the neck of the archegonium towards it. One sperm unites with the ovum and the product of this fertilization, the zygote, grows into a new fern plant.

Sexual reproduction in ferns depends on the presence of water which is necessary for the sperms to swim to the ova. Hence, ferns are apt to be limited to damp places, for, although the large fern plant bearing the spores is able to grow in an exposed place, the prothallus cannot survive except in a damp place. Since there can be no new fern plant without the intermediary of the prothallus, ferns are not very successful in competition with flowering plants. Only the bracken fern is on the increase and is succeeding against the competition of

flowering plants. However, the spread of bracken is due to a very successful vegetative method by means of rhizomes.

We have mentioned ferns to show you that some plants have freely swimming male gametes, the sperms. In the next chapter we shall see that the sexual reproduction of animals involves freely swimming sperms.

QUESTIONS

1. *Answer both parts :*

(*a*) *Devise an experiment which shows that insects are attracted to flowers by the petals.*

(*b*) *Describe the method of pollination in any flower which is pollinated by a bee.*

2. *By means of definite examples describe how wind assists* (*a*) *pollination,* (*b*) *dispersal of fruits and seeds.*

3. *By what means are plants conveyed to a patch of new ground, such as a bombed site ? Mention at least six different plants which you would expect to appear.*

4. *Answer the following :*

(*a*) *Annual weeds are a great nuisance in gardens. What steps can you take to ensure that they are kept in check ?*

(*b*) *By reference to three definite examples show how the gardener makes use of vegetative reproduction.* (*See also Chapter I.*)

5. *Describe the changes which take place after fertilization in the following : rose, gooseberry, clematis, avens. How are the seeds of these dispersed ?*

CHAPTER XIV

REPRODUCTION IN MAMMALS

REPRODUCTION IN THE RABBIT

Mammals can only reproduce by a sexual method; unlike some plants they have no power of detaching parts of their bodies to live as independent units. We shall see that sexual reproduction in mammals shows some resemblance to that in plants. Fertilization takes place between a male gamete and a female gamete and the zygote starts to develop into an embryo within the body of the parent. As in plants, the net effect of the sexual method is multiplication, because many fertilizations occur during the lifetime of an individual, and every zygote is a potential offspring.

Sexual organs.—The male gametes are called **sperms** and are produced in the two **testes** of the male mammal. The testes are contained in a pair of sacs which project between the hind limbs (Fig. 79). Each sac is a continuation of the body cavity. From the testis leads a curved tube, the vas deferens, which joins the urethra (see page 120) just below the bladder. The urethra traverses a projecting organ, the penis. The sperms are carried to the outside with the urine. There are various glands which pour secretions on the sperms as they pass through the vas deferens and the urethra. The sperms are extremely minute, each consists of a head, containing the nucleus, and a long whip-like tail.

The female gametes are called **ova**, and are formed in the two small **ovaries** attached to the dorsal wall of the abdominal cavity (Fig. 22). Large numbers of immature ova are present in the ovary, and, at fairly regular intervals of about a month, several ova develop fully and drop into the **oviducts** beneath. The mature ovum is only $\frac{1}{100}$ inch in diameter. Each oviduct is continuous with a wider muscular tube, the **uterus.** The uteri of each side unite into a central tube, the vagina; this

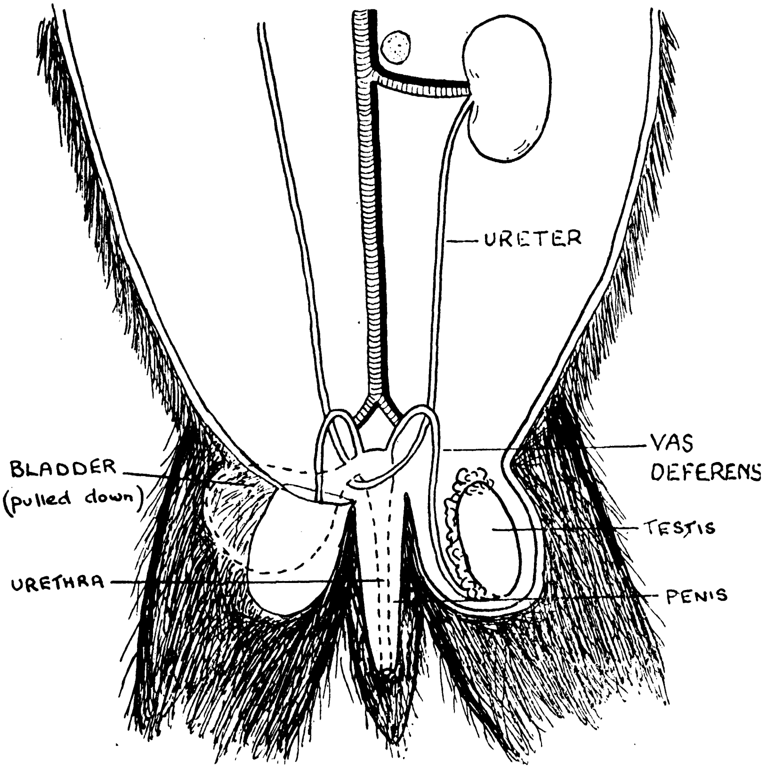


FIG. 79.—Reproductive organ of a male rabbit with one sac cut open to show testis.

is joined by the urethra from the bladder. The common tube formed by vagina and urethra is called the vestibule, and it leads to the exterior at a slit-like opening, the vulva.

Fertilization.—Rabbits can breed from the age of six months at regular intervals during spring and summer, and they have four or five families a year. A normal litter consists of five to eight rabbits, and so it is small wonder that, unless they are checked, rabbits are a very serious menace. Preparations for breeding take place at the end of a special burrow which has only one opening to the outside. Here the female constructs a hollow which she lines with her own fur to make a nest.

The union of sperms and ova takes place in the body of the female, the sperms being introduced by the process of **mating.** During mating the animals approach closely, the male usually mounting on the female's back. The penis of the male, which is normally soft and flabby, becomes hard and erect by the pumping into it of extra blood. In its firm erect condition the penis is easily thrust into the vulva of the female up into the vestibule. Sperms are discharged through the urethra and they swim up the vagina to the uteri and the oviducts. Ova are discharged through the oviducts after the mating process and then fertilization takes place. There is a definite attraction between sperms and ova; perhaps the sperms react positively to some chemical secreted by the ova. Sperms cluster thickly round an ovum, and one penetrates it head end forwards (Fig. 80). Thereafter the other sperms are no longer attracted; only one sperm can penetrate. This sperm loses its tail, and the head part gradually penetrates right into the ovum, and fuses with it. The wastage of sperms is enormous, each testis discharges millions of sperms, and many of these fail to survive the long journey through the coiled tubes and the vas deferens to the urethra. Many more perish during mating and the subsequent swimming up to the oviducts. Sperms are particularly sensitive to acids, and although the fluids secreted by the male glands are alkaline, this does not always protect them sufficiently in the acid environment of the vagina. Of the sperms which survive until they reach the oviducts, the majority die, since there are so few ova in comparison with sperms.

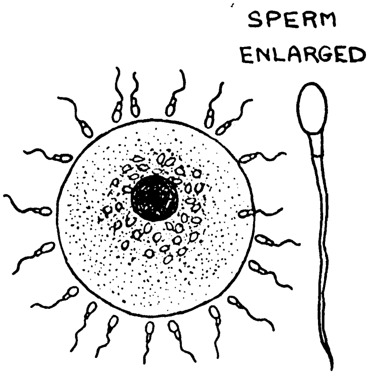


FIG. 80.—Sperms attracted to an ovum.

Events after fertilization.—The fertilized ova or zygotes grow into embryos. They start to divide into many cells at

once. The balls of cells attach themselves firmly to the walls of the uterus. At the place of attachment a swollen projection develops, made partly of parent tissue and partly of embryo tissue; this projection is called the placenta, and the developing embryo is attached to it by a stalk called the umbilical cord. Surely protected inside the uterus the young rabbit grows and develops (see Fig. 81). One of the earlier organs to appear is

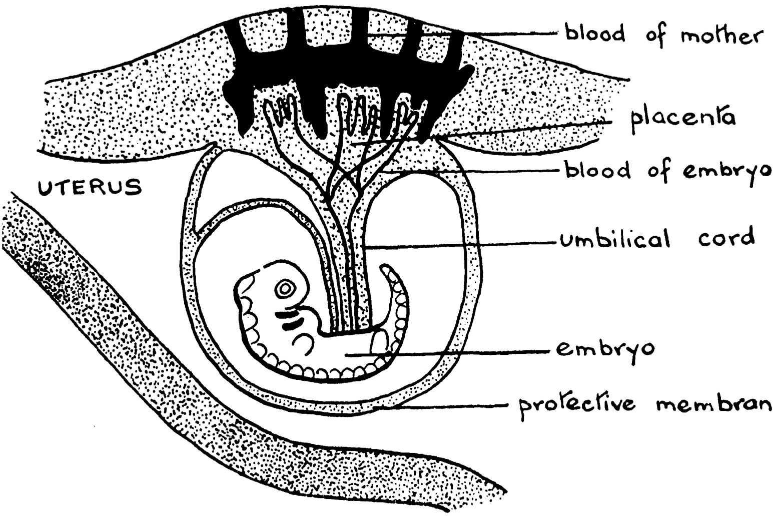


FIG. 81.—Embryo of mammal developing in uterus.

the heart, which is soon linked up with a network of blood vessels running through the umbilical cord into the placenta. Here the blood vessels are very near to a similar network of parental blood vessels (see Fig. 81). The blood vessels of the embryo and the mother are not continuous, but they are sufficiently close together for exchanges of materials to take place very easily. The embryo's blood acquires its oxygen by diffusion across from the blood of the mother; similarly, dissolved food diffuses across from mother to embryo. Waste products of metabolism in the embryo, such as carbon dioxide and urea, diffuse across in the opposite direction from embryo to mother.

Development of the embryo continues inside the uterus for

about a month and, during this time, the uterus enlarges considerably. Every fertilized ovum does not necessarily complete successful development, some fail to attach themselves to the uterus and some die even after attachment; on the average about six embryos complete successful development. At the end of the month the muscular walls of the uteri and the vagina start to contract and relax and squeeze on the embryos. These become detached from the placentas and are gradually extruded to the outside through the vagina and vulva. This process is **birth.** The placentas are shed afterwards. The newly born rabbits are naked and blind. They have to achieve one great change immediately if they are to survive, and that is, they must start to use their lungs, since oxygen is no longer passed from the mother's blood.

During the first few weeks of life they are fed by the mother on milk from glands in her thorax, the mammary glands. These have been developing ever since mating, and the young rabbits suck out the milk from the nipples. This method of feeding the young is called **suckling** and it is peculiar to mammals. The young rabbits gradually develop fur, their eyes open, and they feed themselves on grass after a few weeks.

HUMAN REPRODUCTION

Man is a mammal in all his life processes and reproduction is no exception. Fig. 82 shows the human reproductive organs, and you will see that they are like those of the rabbit. The chief differences concern the female organs; there is one central uterus continuous with the vagina, instead of two uteri, and the vagina has its own exit to the exterior instead of joining the urethra. In the male there is one sac behind the penis and this houses both testes.

Humans take much longer to become sexually mature than do rabbits. Children have testes or ovaries as the case may be, but they do not function, the testes do not produce sperms nor the ovaries ova. The age when the sexual organs start to work is called **puberty**, it is at about 12 to 15 years of age. After this age sperms are shed periodically throughout life. From one or other of the ovaries one ovum is shed at regular

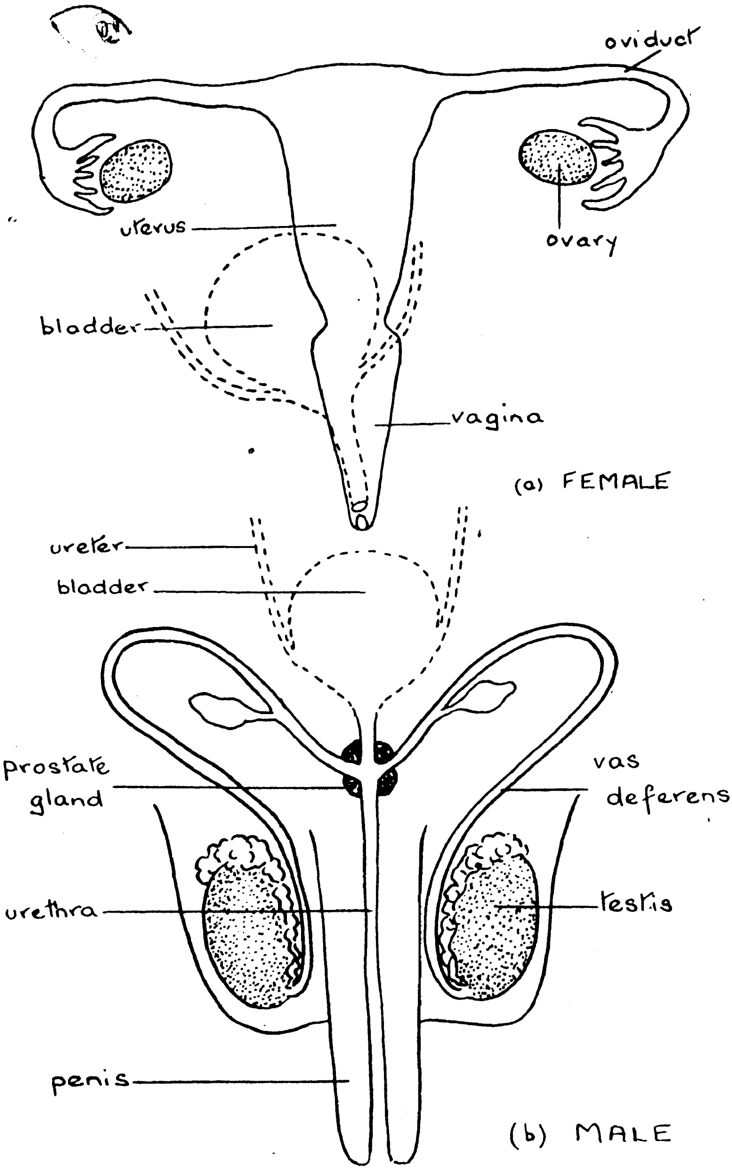


FIG. 82.—Human reproductive organs.

monthly intervals from puberty until about the age of 45. The vast majority of the monthly ova are never fertilized and after three or four days the ovum dies. Then a few days later the lining of the uterus gradually disintegrates and is discharged together with a good deal of blood. This discharge is called the **menstrual flow** and takes about 5 to 7 days. Gradually a new lining develops and enlarges considerably by the time the next ovum is shed.

Mating in humans is not desirable until after the age of 19 or 20. It takes place by the insertion of the man's penis into the woman's vagina, the man stretching himself on top of the woman to effect this. If an ovum has been shed it is fertilized by one of the sperms in the uterus. The sperms are able to live for a week after being introduced into the uterus, and the ovum can live for three or four days after being shed. This gives some opportunity for the ovum to be fertilized to form a zygote. The zygote starts to divide and implants itself into the wall of the uterus where it becomes attached to a swollen placenta by an umbilical cord. After the implanting of the zygote changes take place in the ovary and a hormone is formed which prevents the menstrual flow and which stimulates enlargement of the mammary glands in the breast. This hormone is produced by a special mass of cells in the ovary called the corpus luteum.

The embryo develops in the uterus for a period of nine months (Fig. 83). After a month many of the important organs are represented, including heart, brain, muscles and eye, but the embryo does not look much like a human being at this stage. It has a prominent tail. In the second and third months the embryo becomes more recognizably human, the tail is overgrown by the rest of the body and the limbs develop. In the remaining months before birth the chief change is one of enlargement; in particular the limbs enlarge relatively more than the head, so that the proportion of the head to the limbs gradually becomes less.

Birth takes place, as in the rabbit, by the contraction of the uterus and vagina aided by various abdominal muscles. The newly born baby must start to use its lungs at once, and the

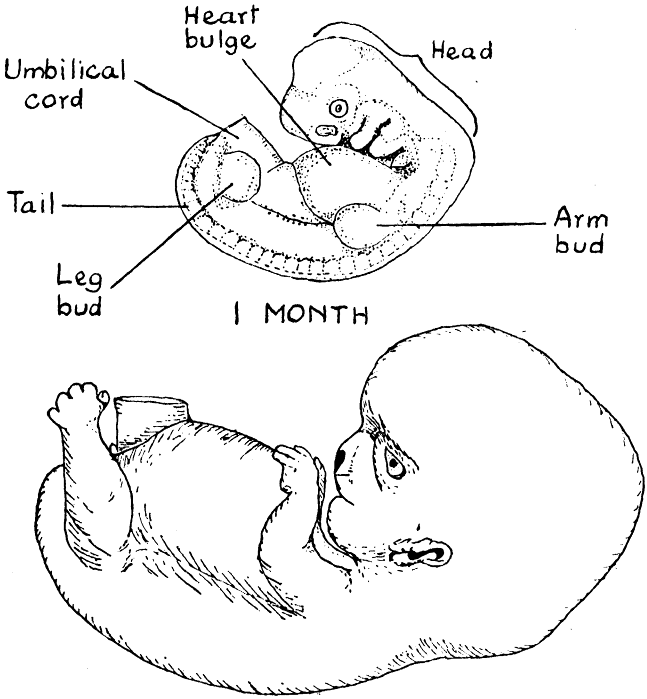


FIG. 83.—Human embryos.

usual sign that this has been achieved successfully is a cry. The baby is suckled by its mother for about nine months. Suckling is sometimes too great a strain on the mother and then the infant can be fed on specially treated cow's milk, which has been modified to make it as much like human milk as possible. Gradually the corpus luteum in the ovary disintegrates together with its hormone. In the absence of this hormone the mammary glands become reduced and the menstrual flow starts again.

It is usual for one baby to be born at a time, but twins are by no means uncommon. They result from the development of two separate ova, or from a single ovum which divides completely into two before implanting. Quadruplets and

even quintuplets are sometimes heard of. The simultaneous development of several babies means that each one is smaller than normal and newly born quadruplets have to be given very special care if they are to survive.

Whereas young rabbits soon become self-supporting and independent of their parents, growing up in human beings is a more prolonged process and parental care lasts for many years. In fact, as we shall discuss in the next chapter, it is difficult to say exactly when a man or a woman reaches maturity.

Periodical shedding of ova does not continue throughout a woman's life. About the age of 45 the ovaries become less active, gradually no more ova are shed, and the menstrual periods cease. On the other hand, the activity of the testes of the man continue throughout life.

QUESTIONS

1. *How does fertilization take place in a named mammal? Describe the subsequent events after fertilization until the growing animal is quite independent of its parent.*

2. *Compare the chances of (a) successful fertilization, (b) successful development of the new organism, in rabbit, flowering plant and fern. (See also Chapter XIII.)*

CHAPTER XV

GROWTH

In the preceding two chapters we have seen that flowering plants and mammals start life as a single cell, the zygote or fertilized ovum which grows into the adult. What do we mean by growth ? For one thing, it is increase in size, and this is remarkable enough when we consider that the oak tree and daisy, mouse and elephant alike all start life as single cells. But even more remarkable than increase in size is the orderly pattern of development. The zygotes of both mouse and elephant seem similar, and yet their patterns of development are so very different. Even in one and the same animal or plant development is a great mystery. After fertilization the zygote of a mammal divides into a large number of cells which are all alike and yet at a later stage there is a marked difference in their destination ; one block of cells is destined to be the central nervous system, another the muscles, and so on. Scientists are just beginning to understand the causes of development but they do not know very much as yet. Let us be content with finding out something about *how* flowering plants and animals grow and develop and leave the more vexed question of *why* they do these things.

GROWTH IN PLANTS

Conditions for the Germination of Seeds.—Seeds have already undergone some development before they are shed from the parent, and we saw in Chapter XIII, page 160, that a seed contains an embryo plant which is furnished with a store of food either in its own cotyledons or in a separate tissue called the endosperm. Fig. 84 shows the structure of a broad bean seed.

A resting seed is, of course, alive but inactive. It looks dry and wrinkled but actually it does contain some water. You can convince yourself of this by heating some dry peas in a

clean test-tube and you will see that a mist condenses on the upper part of the tube. Before growth can take place the seed absorbs a great deal of water and increases considerably in size. You are familiar with the difference in appearance between soaked peas and dry peas. If water is withheld the 'dry seeds' remain inactive. You have probably kept packets of seeds from one year to another and realize that they remain capable of germinating for a long time, but not indefinitely. The time during which seeds can retain their vitality varies from plant to plant; willow seeds remain alive only for a few days, while wheat grains will still grow after 12 years.

After the absorption of water, enzymes become active in the food store and convert insoluble substances into soluble substances which can be transported to the radicle and the plumule. Here cell division and cell enlargement proceed actively, using the food materials and the water. For the first stages of growth the food store in cotyledons and endosperm provides all the necessary materials. You can do a simple experiment to find the effect on growth of curtailing this food store.

Experiment 42.—Soak six broad bean seeds for two days and then peel off all the testas. Have ready three gas-jars containing water, each with a cork wedged in a vertical position in the neck. Fix two of the soaked seeds by pins through the cotyledons on either side of one of the gas-jars so that the radicle just touches the water. Cut off one cotyledon from two other seeds, being careful not to damage radicle and plumule, and fix them in a second gas-jar. From the remaining two seeds cut away both of the cotyledons with the exception of a very small part to put the pin through; fix these in the third gas-jar. Subsequently, the very poor growth made by the seed from which cotyledons were practically removed, will convince you of the importance of food supply. You will probably find that the seeds with just one cotyledon make as good growth as those with two: the bean has an unusually large food supply, and one cotyledon contains quite enough to enable the plumule to become a shoot with green leaves, and, as soon as leaves are formed, the plant can make its own food.

Food and water alone are not sufficient for growth, for active cell division and enlargement necessitates energy which must be released from some of the food by oxidation. Germinating

seeds respire actively and must have a good air supply from which to absorb the oxygen. Seeds will not grow in thoroughly waterlogged soil because of the shortage of air. You can do an experiment to show that seeds require oxygen to grow.

Experiment 43.—Plant mustard seeds in two soaked sponges. Have ready two gas-jars, one a quarter full of water, and the other a quarter full of alkaline pyrogallol. Alkaline pyrogallol is made by mixing equal quantities of 3 per cent. pyrogallol and 5 per cent. potassium hydroxide immediately before use, and it has the power of absorbing oxygen. Wedge a sponge containing seeds in each gas-jar, and cover each jar with a greased lid, being sure to make an air-tight connection. After a few days you will see that the seeds in the sponge over water have grown, but in the sponge over the pyrogallol there is practically no growth. There may be a few roots showing because most seeds are capable of a very little respiration without oxygen, but this is a very limited ability, and growth soon ceases (see Anaerobic Respiration in Chapter XIX, page 238).

Temperature has a considerable effect on the germination of seeds, as you can show by a very simple experiment.

Experiment 44.—Plant three sets of mustard seeds in December; put one set outside, one in a heated room, and one in an unheated room. Keep a record of the temperature in these places for a fortnight and compare it with a record of the growth made during this period.

Thus, the essential conditions for germination of seeds are food supply, water supply, oxygen supply and suitable temperature. Seeds contain their own food supply and there is abundant oxygen in the air, so, unless the temperature is very unsuitable, to make seeds grow it is merely necessary to give them water, and this can be done by planting them in soil. Some plants have seeds which will not germinate immediately they have been shed from the plant even if all the essential conditions are supplied; they go through a period of dormancy before germination is possible. Examples of such plants are lesser celandine, apple, hawthorn, lime and broom. However, the seeds of all the plants commonly cultivated on farms and allotments have no such dormant period and will grow immediately after they have been harvested.

Structural Changes during the Germination of Seeds.—Now let us see what structural changes accompany the germination

of seeds. Always the radicle is the first organ to elongate and burst through the testa (Fig. 84 (*e*)). Large seeds, such as beans, are planted with radicles pointing downwards, but the majority of seeds are much too small for this to be possible. However, you will remember that roots are positively geotropic

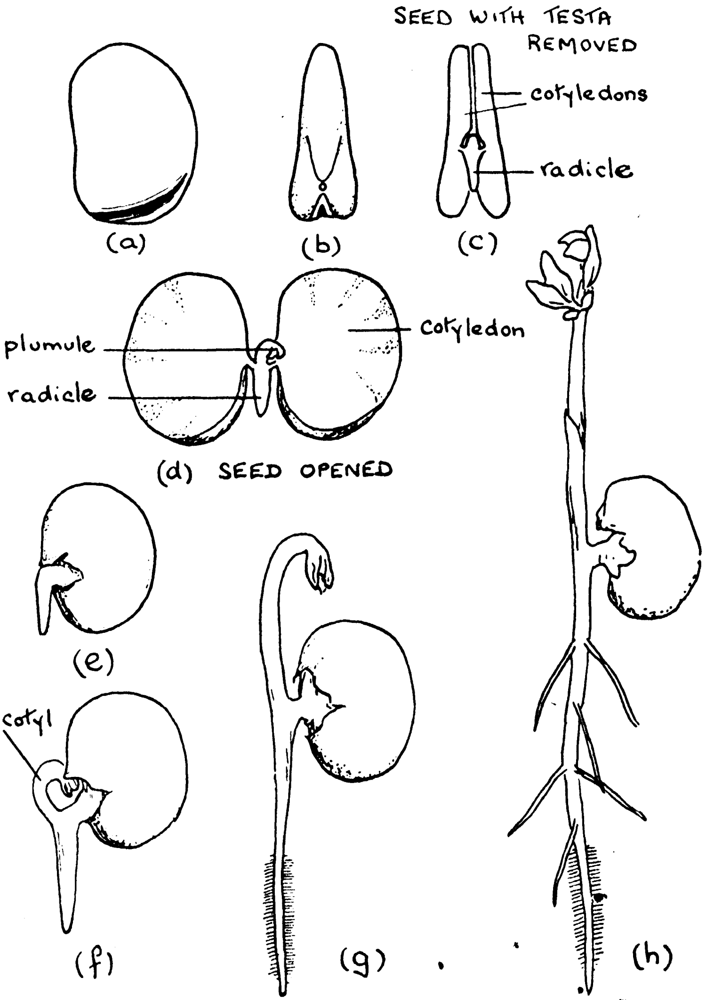


FIG. 84.—Germination of broad bean.

and, if the root emerges horizontally or upwards, a growth curvature soon brings it into the downward direction. In the broad bean seed the shoot is pushed out of the seed by the elongation of the region just above the cotyledons. This region is called the epicotyl, and by its elongation the shoot is pulled out of the seed in an arched position (Fig. 84 (*f*)). The arched shoot pushes its way through the soil (Fig. 84 (*g*)), and you will notice that the leaves are still folded and protected on the inner side of the arch. Later, the shoot straightens out and the leaves start to unfold (Fig. 84 (*h*)). All this time the cotyledons are still below the soil and have been supplying food for these changes. Once the leaves are formed the plant is no longer dependent on the cotyledons. Other seeds which

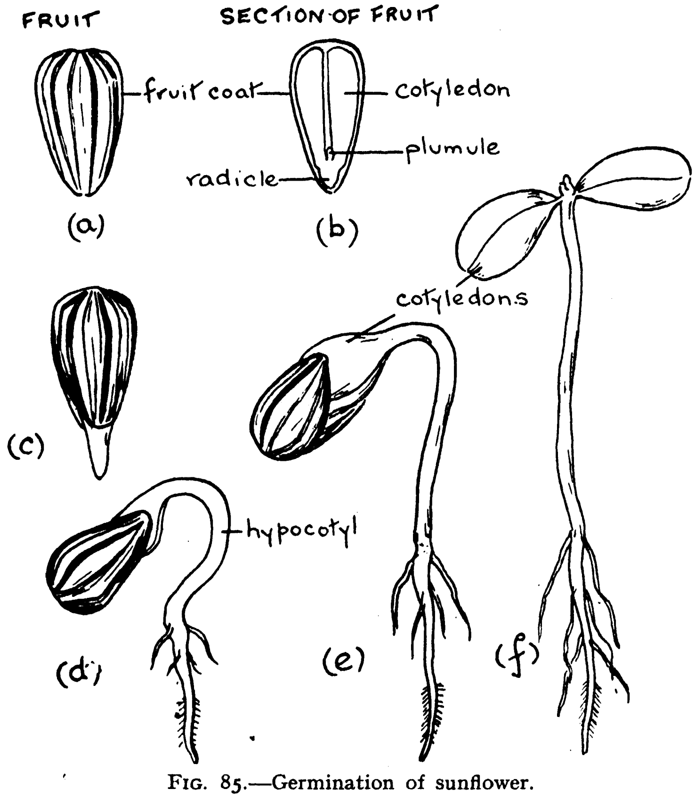


FIG. 85.—Germination of sunflower.

germinate in a similar way to the broad bean are oak, horse chestnut, and pea.

The majority of seeds behave in a different way when they germinate. If you are a gardener you will know how difficult it is to recognize plants in the early stages of their growth. For many of them produce a pair of first leaves which are quite unlike the normal leaves of the plant. These first leaves are the cotyledons which have been brought up above the level of the soil. After the root has emerged (Fig. 85 (*c*)) the part of the shoot just below the cotyledons, the hypocotyl, starts to elongate and forms an arch to which cotyledons are attached (Fig. 85 (*d*, *e*)). When the arch has straightened out the cotyledons expand and become green leaves (Fig. 85 (*f*)). In these seeds the cotyledons first act as food stores and then as photosynthetic organs. They fall off later when the normal green leaves are formed.

The seeds of cereals have a special structure (Fig. 86), and, as you would expect, their germination is peculiar to themselves. The food is stored in an endosperm and the single cotyledon of the embryo has three parts. One part is shield-shaped and forms a barrier between the endosperm and the rest of the embryo ; it acts as an absorbing organ. The other two parts form sheaths round the radicle and plumule respectively. During germination the root emerges first, bursting through its sheath. Then the shoot

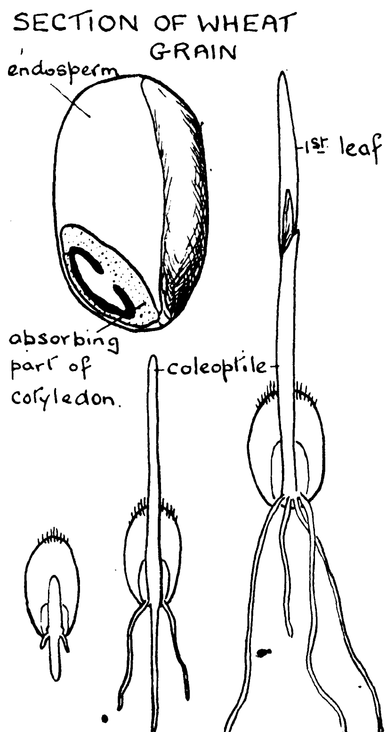


FIG. 86.—Germination of wheat.

sheath part of the cotyledon, called the coleoptile, elongates and pushes its way above the surface of the ground as the first spear-shaped leaf. Subsequently the next leaf pushes its way out through the coleoptile and the second leaf through the first leaf and so on (Fig. 86).

Plant Hormones.—There exist certain internal controllers of growth within the plant itself. An oat coleoptile grows chiefly by the enlargement of cells which are already there. A Dutch scientist called Went found that if oat coleoptiles were decapitated growth ceased, the cells remained small and did not enlarge. By placing the tips on again growth was resumed and this looked as though the tips were producing some material substance which affected enlargement in the region below. This supposition was tested by placing the tips on a thin layer of jelly for 24 hours in the hope that, if material substances existed, they would diffuse into the jelly. When small pieces of the jelly were put on decapitated tips growth was resumed, showing that the jelly did indeed contain growth promoters. The growth-promoting substances are known as **plant hormones,** or growth substances. Experiments are being extended beyond the oat, and it seems likely that the growth of most shoots is controlled by hormones produced in the tips. Extracts containing plant hormones are now on the market for promoting root growth from cuttings.

Vegetative Development and the Life Cycle.—We discussed the conditions for seed germination at some length, and much the same conditions determine the growth of the plant through its life, viz., food supply, water supply, oxygen supply and suitable temperature. In the developing plant the food has to be made, and hence healthy growth depends on all the conditions for photosynthesis and on a good mineral salt supply (see Chapter VII). Also, you will remember, from Chapter XII, that light has an influence on growth rate quite apart from its effect on photosynthesis. The rate of growth in the dark is faster than in the light, but the shoots produced are weak and etiolated.

The more the plant grower can regulate conditions for growth to suit his particular crop the bigger his yield will be. On a

large scale on farms, soil conditions, including mineral salt supply, are the only ones which can be regulated (see Chapter III). On a small scale in greenhouses, temperature may also be regulated. Temperature is a most important factor in the growth of crops, the optimum temperature being that at which the most sturdy growth is made. High temperatures may cause fast weakly growth. The growing of flowers in pots is often carefully controlled by temperature. If you are growing bulbs in bowls it is advisable to keep them at a comparatively low temperature, say that of an unheated room in winter, until they are almost ready to flower. Then they grow slowly and very sturdily. When the buds appear you can transfer them to a heated room when they open very quickly. The range of temperature permitting growth varies with the plant; for wheat it is from 0°–42° C., for maize it is from 10°–46° C. Such ranges of temperature determine the range of latitudes in which plants can grow.

Annual plants grow vigorously throughout life; they flower, set seed and then die. Perennial plants in our climate show seasonal periodicity in growth. Growth proceeds actively in spring and summer and some time during this period flowers are formed. During the period of active growth a good deal of food is stored. Then, towards the end of the summer, growth gradually ceases, perennial herbs die down to ground level, deciduous trees shed their leaves and all kinds of perennials go into a resting condition until the following spring, when the buds develop at the expense of the food store. The dormancy of buds during the winter is not caused solely by low temperature, nor is the opening of buds in the spring due to raised temperature alone. If you bring tree twigs into a warm room in mid-winter, they show no sign of development, but in the spring, they develop readily even though the temperature is just the same as before. There seems to be some inherent rhythm in perennial plants, and it is only with great difficulty that they may be stimulated to grow during the usual dormant period. Drastic treatment with ether vapour or immersion in hot water will sometimes cause buds

to open, and the forced lilac which we see sometimes at Christmas has had such drastic treatment.

The development of wild plants depends very much on external conditions and the vegetative appearance may vary considerably. Fig. 87 shows leaves from two different dandelion plants, one growing by a dry roadside and the other growing in a damp place among grass. Such plants look so different that it is only when they flower that their identity is certain. That is why flowering plants are usually classified by flower characters and not by vegetative characters.

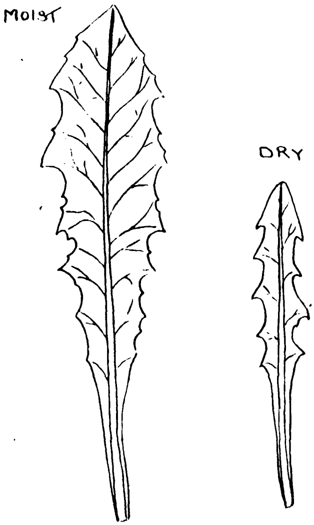


FIG. 87.—Dandelion leaves—for explanation, see text.

GROWTH IN MAMMALS

Whereas plants grow throughout their lives, mammals grow chiefly in their youth ; they attain their maximum size which persists, more or less unchanged, throughout life. Of course, other changes take place other than mere increase in size ; for instance, the animal becomes sexually mature and its intelligence also develops. The exact age when an animal may be said to become adult is difficult to assess. For one thing development is a very gradual process, there is nothing sudden and final about it. For another thing the age of becoming adult will vary according as we define adulthood as attaining maximum size, as attaining sexual maturity or as attaining maximum intellectual ability. In a human being 21 years as the age of becoming fully grown up is a convention ; a man is sexually mature before this, he may or may not have finished increasing in size and his mental powers have certainly not attained their fullest development. As a matter of fact if

man's mind is used as the criterion of his being grown up it is doubtful if he is adult before he is forty at least.

Mammals need the same conditions for growth as plants, viz., food, oxygen, water and suitable temperature. Growth is also regulated by various chemical controllers or hormones. The effect of diet on growth was discussed in Chapter VIII (pages 99 to 103), and the effect of hormones on growth was discussed in Chapter XI (page 145). You are advised to read the relevant parts of these chapters again.

QUESTIONS

1. *What are the chief parts of a seed? With the help of diagrams describe two different ways in which the cotyledons may behave during germination.*

2. *Five bean seeds are soaked and then treated as follows:*
(*a*) *Planted in dry soil.*
(*b*) *Planted upside down in moist soil.*
(*c*) *Cotyledons cut away and planted in moist soil.*
(*d*) *Planted in moist soil and put into a dark cupboard.*
(*e*) *Submerged in a gas-jar full of water.*
Describe and explain the subsequent developments of the seeds.

3. *What are the optimum conditions for the healthy growth of a crop? To what extent can the farmer ensure that the conditions for the growth of his crop are optimum?* (*See also Chapters III, VII.*)

4. *What do you know of the effect on animal growth of the following: thyroid gland, pituitary gland, vitamin A, vitamin D? What is the chief difference between the growth of a mammal and the growth of a flowering plant?* (*See also Chapters VIII and XI.*)

CHAPTER XVI

VERTEBRATE ANIMALS

So far our studies of animals have been confined almost entirely to mammals which are usually regarded as the highest class of animals. Now, in very broad outlines the living processes of all animals are similar, all must digest and assimilate food, all must respire, excrete, grow and reproduce. Hence your knowledge of the living processes of a mammal is a useful basis for the study of other animals. All the many and varied kinds of animals are usually classified into two groups, viz., **Vertebrate Animals,** which have a backbone, and **Invertebrate Animals,** which have not.

Mammals are the highest class of the vertebrate group ; they are warm-blooded furry animals which suckle their young. Other classes are birds, reptiles, amphibians and fishes. Let us consider briefly the chief features of these other classes. In each class we shall refer particularly to one or two representative animals ; it must not be assumed that all birds are exactly alike any more than that all mammals are exactly alike. Therefore, we shall study birds as represented by the pigeon and fowl, amphibians as represented by the frog, and fishes as represented by the goldfish and herring.

BIRDS AS REPRESENTED BY PIGEON AND FOWL

Flight.—The way of life of a bird is largely dependent on its feathers, details of which are shown in Fig. 88. The vane of a feather consists of many closely arranged barbs which are attached to one another by minute hooked structures called barbules. Thus the vane is a continuous surface and this is of great importance in flight.

The movement of a pigeon's wings is not a simple flapping up and down. The upstroke lifts the wings vertically above the back. On the downstroke they beat powerfully forwards and downwards and then backwards. In performing these

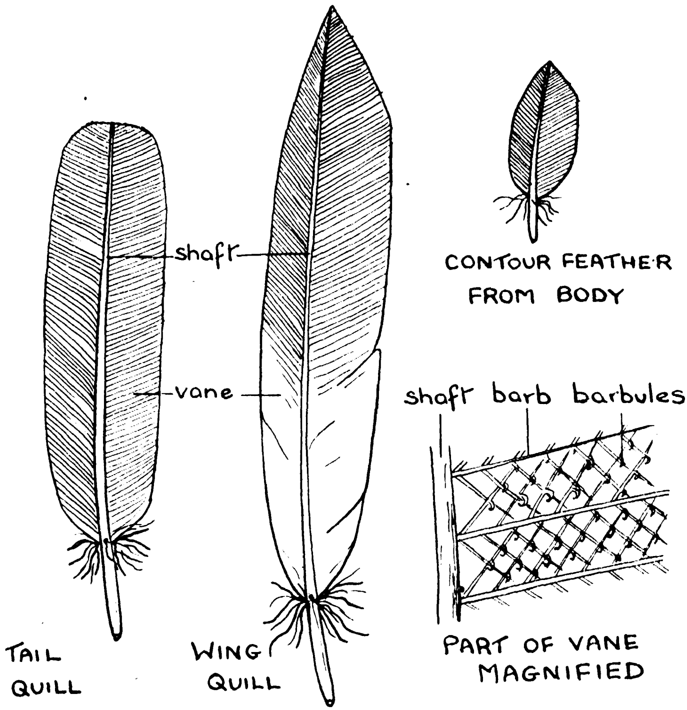


FIG. 88.—Feathers of pigeon.

movements the tip of each wing describes an asymmetrical figure-of-eight movement as shown in Fig. 89.

It is the powerful downstroke of the wing which causes the pigeon to rise on the air. The wing surface beats on the air, thus increasing the pressure below it and the increased pressure lifts the bird. The whole mechanism depends on the wing surface being airtight. If there are any spaces in the wing, air will leak through and it will not be possible to have a higher pressure on the lower side of the wing than on the upper. We have seen how the interlocking barbules enable the vanes of the feathers to present a continuous surface. Fig. 89 shows the arrangement of the wing feathers in an outspread wing, and you will notice that the feathers overlap one another. During the downstroke the feathers are closely pressed against

each other, thus ensuring a continuous surface. On the upstroke the feathers separate and air readily passes between them, hence the bird is not pushed down on the upstroke. A bird steers itself in the air by using one wing more strongly than the other.

The wings are moved by powerful muscles attached to the keel-shaped breast-bone. Flying is a much more strenuous activity than running or walking, and the efficient working of the wing muscles depends on very active respiration. Birds

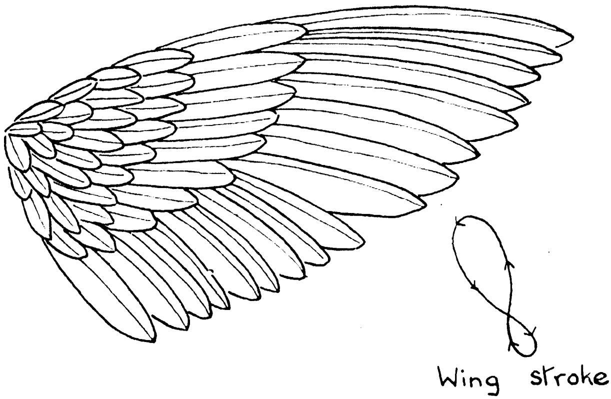


FIG. 89.—Right wing of pigeon.

generate a good deal of heat in respiration, and, as a rule, the body temperature of a bird is higher than that of a mammal. The temperature of a pigeon is 107·6° F.

Fowls seldom fly to any height or for any distance. Their bodies are too bulky and heavy in proportion to the wing span, whereas the pigeon is much lighter in proportion to its wing span. Lightness is a feature which is a great aid to flight. So also is the general shape of a bird's body; with its legs tucked up it is almost perfectly streamlined. The part played by the tail is also significant; the tail feathers can be spread fanwise or they can be close together. In the air the tail fan acts as a balancing organ, while, when the bird lands, the tail acts as a brake.

Pigeons fly easily and efficiently, but to see bird flight at

its best you should watch the graceful sweeps made by seagulls and the quick darting to and fro of martins. Seagulls often sail or glide in the air without any up and down movements of their outspread wings. It is thought that in gliding the wings are making use of air currents in much the same way as do glider planes.

Nutrition.—The diet of birds is very varied. Only a few feed on the wing, such are martins and swallows, which catch insects as they dart through the air. Pigeons are vegetarians and will eat grain, berries and green shoots of all kinds. Similarly, fowls are vegetarians and thrive well on a diet of grain, bran and greenstuff. Fowls are also given grit to eat, and wild birds pick up small stones and grit which they swallow. Contrary to a popular belief, this grit has nothing to do with the making of egg-shells, it is concerned with the grinding up of food. A bird has no teeth ; it uses its beak to do a certain amount of cutting up, but, for the most part, the food is bolted with very little breaking up. A bird's gullet contains an expanded bag or crop in which the bolted material is stored. The crop of a pigeon contains entire grains, berries, leaves and so on. The grinding up of the food is done with the help of the grit in the stout muscular gizzard which represents part of the stomach. The walls of the gizzard are continually contracting and relaxing, and this has the effect of churning up the food with the grit ; hence a grinding action takes place and the food is reduced to a pulpy consistency. As such, it passes into the small intestine where digestion takes place.

Reproduction.—In the female bird the single ovary has particularly large ova (or yolks) and these are well laden with food supply. Internal fertilization occurs by a process of mating which is similar in essentials to that in mammals. The fertilized ovum passes down the oviduct and is coated first with semi-fluid albumen, then by a parchment-like membrane and finally by a shell. At this stage the egg is laid. Fig. 90 shows a section through a hen's egg. Birds make elaborate preparations for the laying of their eggs by building nests. Pigeons' nests are made entirely of twigs and are built by both male and female, who take it in turns to sit on the eggs. This

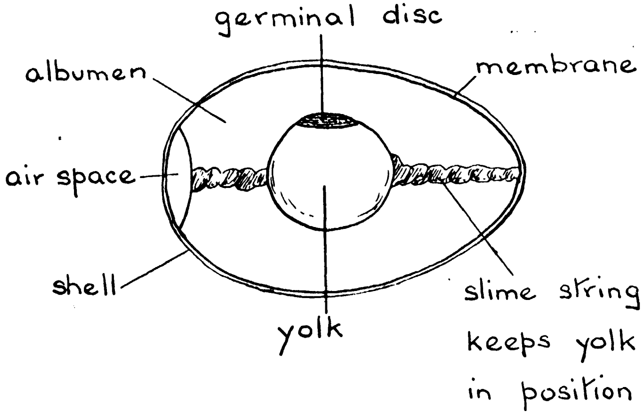


FIG. 90.—Section of bird's egg.

incubation provides a suitable temperature for the development of the young bird from a small disc on one side of the yolk, called the germinal disc, at the expense of the food supply stored in the rest of the yolk. Pigeons' eggs take about a fortnight to hatch, while hens' eggs require three weeks. Young pigeons are naked creatures and are fed by their parents for the first week or two. The parents provide a white liquid which is regurgitated from the crop; this is often called pigeon's milk.

Hens' eggs are not necessarily fertilized; in fact the vast majority of the eggs we buy contain unfertilized yolks. Mating of cock and hen is only necessary to the poultry farmer when he wishes to rear new chicks.

AMPHIBIANS AS REPRESENTED BY THE FROG

Frogs, toads and newts are all amphibians, and the animals belonging to this class spend their lives partly in water and partly on land. Thus, the adult frog is fairly well adapted to an existence on land, but the eggs are laid in water, and the tadpoles, which hatch from the eggs, are entirely dependent on living in water. Even the adult frog usually lives near water.

To make observations on a frog keep the animal in the laboratory for a few days in a wooden case. One side of the

case should have perforated zinc for ventilation and one side should be made of glass. The bottom of the case should be fitted with a zinc tray in which may be placed tussocks of grass and a bowl of water with a stone in it. The frog spends long periods of time in a sitting position, and you will notice that it is well camouflaged by its green, brown and black mottled skin.

You will notice that the floor of its mouth is continually moving up and down. This is a breathing movement by means of which air is drawn through the nostrils into the mouth, where oxygen is absorbed into blood capillaries. When the

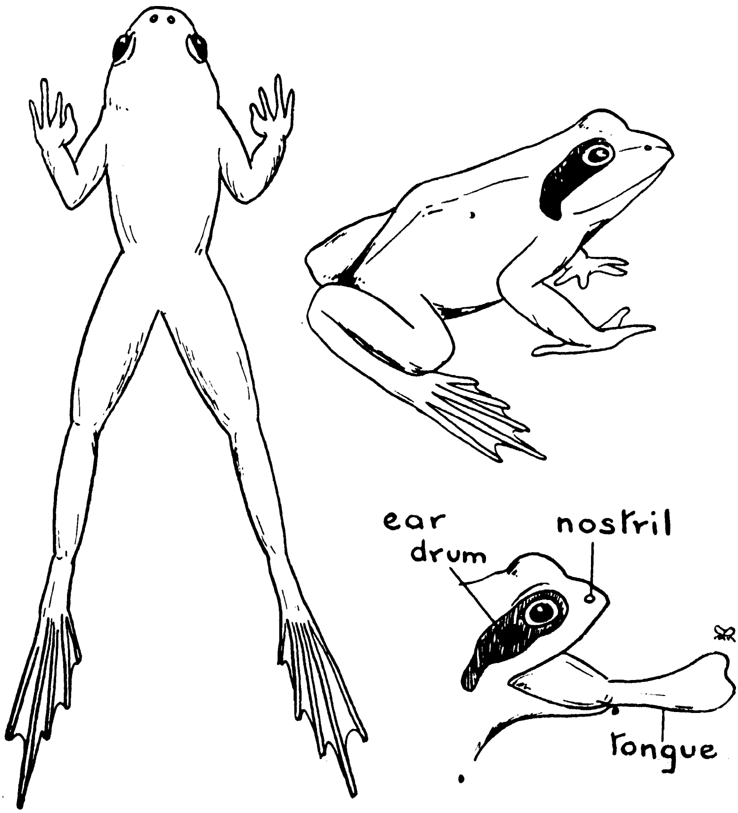


FIG. 91.—Frog.

creature is active it also uses its lungs for breathing. Moreover, it can breathe through its wet slimy skin, and this is the method used under water.

Leaping and Swimming.—Fig. 91 shows a frog in the sitting position and the same animal with the hind legs stretched. The sudden extension of its hind legs acts as a powerful thrust pushing the animal up into the air. When you watch a frog leaping you will see that the short fore legs are of use during landing. Frogs can also walk in an ungainly waddling fashion using all four legs. The long hind legs are the chief swimming organs and are pushed out alternately while the frog is under water. The webbing between the toes of the hind feet is of use in preventing water from leaking between the toes.

Feeding.—Frogs feed on insects, chiefly gnats and small flies which are abundant on the banks of ponds and ditches. If you are keeping frogs in captivity you can feed them on greenfly or small worms. The insects are caught by the tongue of the frog. This is a soft sticky pink structure attached at the front of the mouth and pointing backwards towards the throat. It is flicked out as shown in Fig. 91 and small insects are easily caught on the slimy sticky surface. Before the insect has time to free itself, the tongue returns to the mouth and the insect is swallowed without mastication. The flicking in and out of the tongue is extremely rapid.

Hibernation.—A frog is a cold-blooded animal, its temperature is that of its surroundings and therefore its degree of activity is dependent on the external temperature. In winter, activity is precluded by the low temperature and the creature is in a resting condition; its energy consumption is at a minimum, for it merely has to maintain its protoplasm in a living condition, and hence respiration can be very slow. All other activities, such as growth, feeding and moving, cease. Such a resting condition is called **hibernation.** A frog often hibernates in the mud at the bottom of a pond and, during this period, it obtains the small amount of oxygen which it requires through its skin.

Tadpoles.—The reproductive organs of the frog are shown in Fig. 92. The ova and the sperms develop all through the

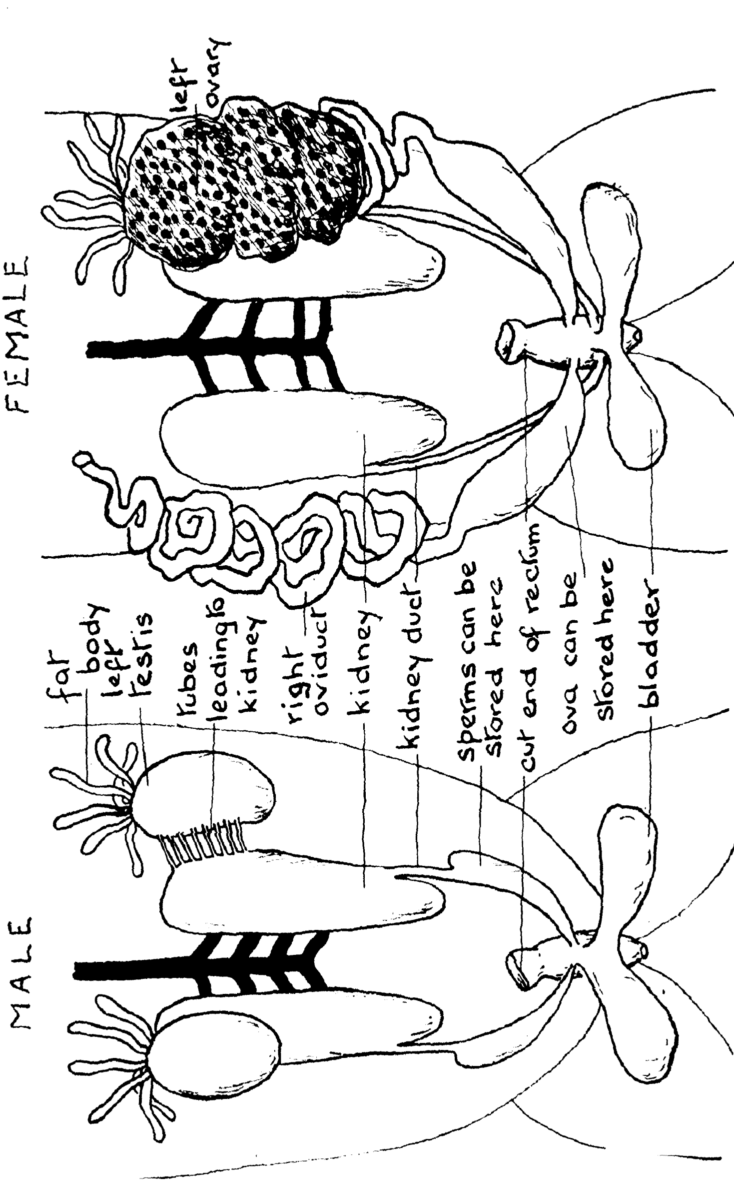


FIG. 92.—Reproductive organs of frog (right ovary of female removed).

summer and are fully formed by the time the frogs hibernate. In March, when activity is resumed, sperms from the testes pass through the kidneys and thence into the ureters and the sperm sacs. In the female the ova are released from the ovaries into the body cavity. Here they find their way into the openings of the long coiled oviducts. They pass down the oviducts and are coated with a layer of jelly. Then they are stored in the wide ovisacs.

At this time of year the frogs seek water and the male frog attracts the female by croaking loudly, then he mounts on her back and clasps her under the arm-pits. In this position the frogs swim round the pond in pairs, while the female discharges her ova into the water and the male squirts sperms over them, so that each ovum becomes fertilized. Notice that this is external fertilization, but, in this case, it is almost certain to be successful because the sperms are shed so near to the ova. A pair of frogs may produce over a thousand eggs. In the water the thin covering of jelly swells considerably and becomes a thick covering.

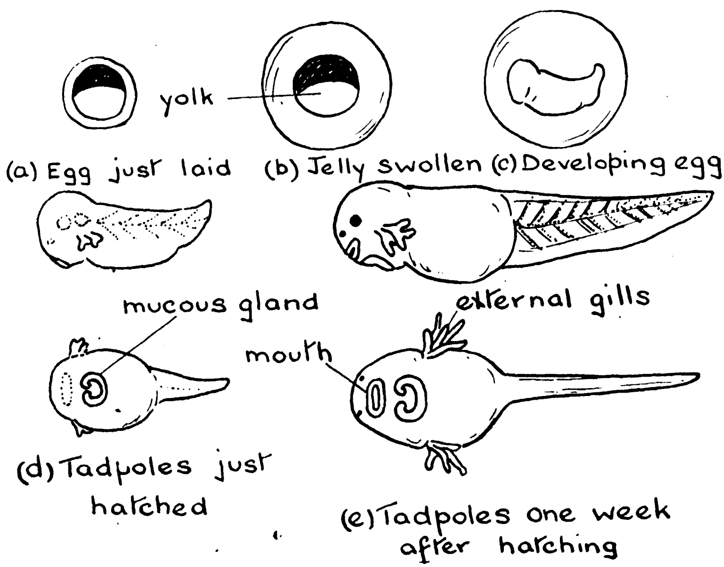


FIG. 93.—Development of a frog's egg.

The eggs develop into tadpoles which hatch after a fortnight (see Fig. 93). Newly hatched tadpoles do not swim about for the first day or two ; they cling on to water-weed by a mucous gland and feed on the remains of the yolk of the egg. After a few days feathery tufts grow out just behind the head ; they are called **gills**, and contain a very good blood supply into which oxygen is absorbed from the water. Now the creature has a mouth and feeds on microscopic plants found on water weed. It swims actively by lashing its tail.

The external gills do not last long, and about 10 to 14 days after hatching they are replaced by internal gills covered by a gill cover. These gills are somewhat similar to those of a fish (see page 206). The tadpole is continually swallowing water which is forced over the gills and then out through an opening of the gill cover on the left side of the body, called the spout. The gills absorb dissolved oxygen from the water. For several weeks the chief change is growth in size. Fig. 94 shows three views of a tadpole about four weeks after hatching. As the tadpole grows in size it starts to eat water-weed, biting small pieces of leaf with its horny jaws. Later, about 5 weeks

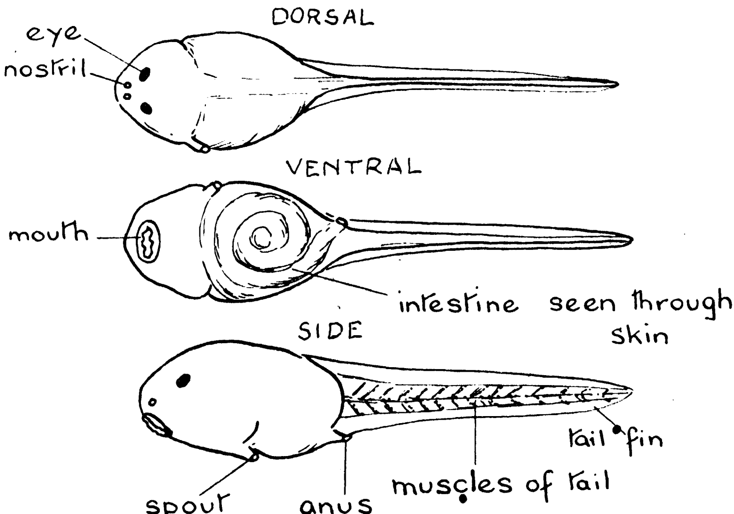


FIG. 94.—Three views of a tadpole about four weeks after hatching.

after hatching, it starts to eat animal food; and if you are keeping tadpoles in the laboratory, from this stage onwards you should feed them about three times a week with a small piece of meat which can be hung on a cotton. Do not leave the meat in the water longer than half an hour.

To all intents and purposes, the way of life of a tadpole is that of a fish, yet tadpoles are not fishes for they develop into frogs. A young free-living animal, which is quite different from the adult, is called a **larva.** The series of changes by

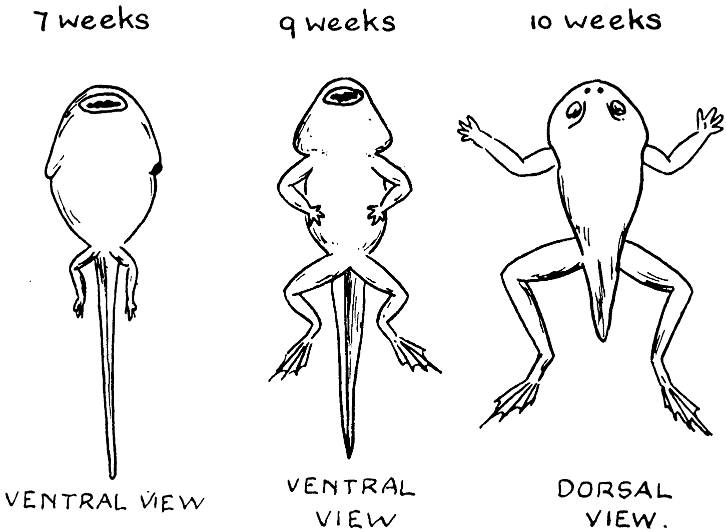


FIG. 95.—Metamorphosis of tadpole, 7–10 weeks after hatching.

which a larva is transformed into an adult is called **metamorphosis.** Fig. 95 shows the stages in the metamorphosis of a tadpole into a frog. Both front and hind limbs start to form about six weeks after hatching, but at first only the hind limbs are apparent because the front limbs are hidden by the gill cover for some time. While the limbs are growing, the tadpole starts to come to the surface of the water for gulps of air into its developing lungs. About ten weeks after hatching, the tail is gradually digested, then the creature sheds its skin and

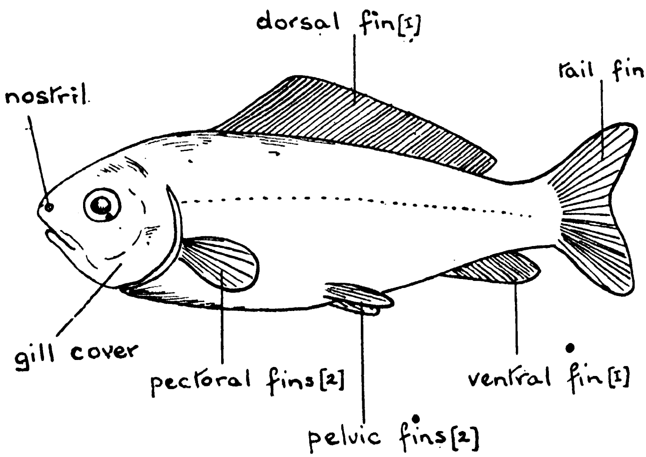
metamorphosis is complete. A frog attains full size and sexual maturity in three years.

Of the many hundreds of eggs laid by the parents very few become mature frogs. Some eggs never hatch, many tadpoles are eaten by other water creatures, and, finally, large numbers of the young frogs leaving the ponds in July are eaten by birds.

FISH AS REPRESENTED BY GOLDFISH AND HERRING

Swimming.—Life in water is a very different affair from life on land. Water is a buoyant medium and, unless there are strong currents or waves, the mechanical problems of the creatures are less than on land. A fish's body has a density which is approximately that of water. Owing to the increasing pressure at deeper levels, there needs to be some mechanism for altering the density of the fish. A fish has an air bladder in the dorsal part of its body cavity, and the volume of air in it may be regulated by the fish, thus ensuring adaptation to the various depths of water.

Arms and legs have not been developed in fish; these are essentially specialized structures associated with life on land. The outgrowths of a fish are called **fins.** They are shown in Fig. 96 and they play some part in swimming. The main



propulsion is effected by a side to side movement of the posterior end of the body and tail, brought about by the powerful dorsal muscles. By this movement a fish takes a slightly zig-zag course through the water. The tail fin acts as a flail ; it increases the surface area for pushing on the water ; the dorsal and ventral fins keep the fish on an even keel, and the paired pectoral and pelvic fins act as stabilizers. Steering is effected by lashing the tail more to one side than the other. You will realize how the streamlined shape of the fish aids its passage

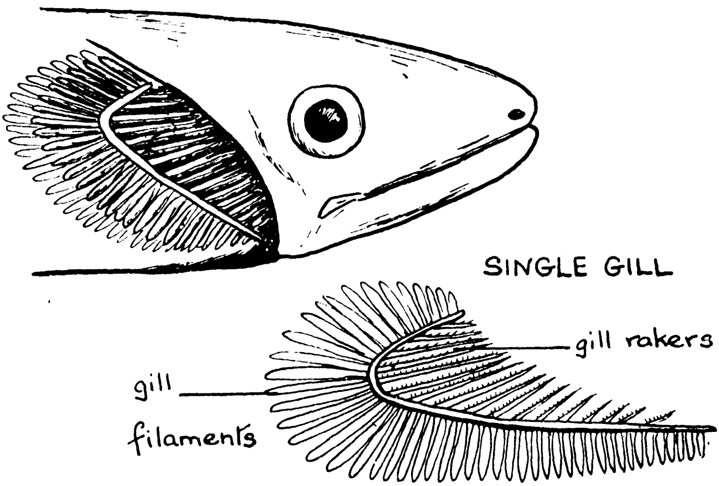


FIG. 97.—Gills of herring.

through the water ; considering the resistance of water, the speed attained by fish is high.

Breathing.—As you watch a goldfish opening and shutting its mouth and the covers behind its head moving, you will realize that these are breathing movements. You may catch sight of the bright red gills under the covers, but you will be able to study the gills in a herring by cutting off the gill cover on one side and examining the gills inside it (see Fig. 97). A fish, like a tadpole, has openings or gill clefts leading from the back of its mouth to the exterior ; these are separated by bony arches to which are attached soft bright red gill filaments.

On the other side of each gill arch are stiff outgrowths called gill rakers. These gill rakers are particularly conspicuous in the gills of the herring. The openings of the gill clefts are covered on each side by a gill cover or operculum attached to the body wall along its anterior and dorsal margins, but free along its posterior and ventral margins. As water is swallowed it is forced through the clefts and out under the operculum. During its passage, the blood in the gill filaments absorbs the dissolved oxygen. To keep goldfish successfully in an aquarium it is essential to keep the water adequately aerated.

Nutrition.—The feeding habits of fishes are very varied. Herrings feed chiefly on very minute plants and animals which live suspended in the water. Such organisms are classed as plankton. The minute plants called diatoms are an important constituent of the plankton, and diatoms are described in Chapter XVIII, page 223. The plankton are taken in with each gulp of water and, as the water passes over the gills, the gill rakers act as a sieve and retain the plankton which are passed into the gullet. You can imagine that many thousands of plankton are needed to nourish the herring, but since every mouthful of water contains some plankton, there is no difficulty about this. Goldfish eat small animals of the shrimp type. When keeping goldfish in an aquarium it is desirable to buy food for them in the form of dried 'water fleas' or dried ant pupæ.

When we were discussing nutrition we said that the food of all animals is ultimately dependent on plants, and the food of water creatures is no exception to this rule. Some sea fish feed directly on seaweeds and some fresh-water fish feed on pond weed. Apart from these, the food of fish is ultimately dependent on plankton. Sharks and whiting feed on other fish, and these other fish have fed on smaller water creatures, which in their turn fed on plankton.

Spawning.—It is comparatively rarely that goldfish spawn in an ordinary aquarium and so we will consider the spawning of herrings. Doubtless you are familiar with the appearance of herring or cod ovaries in the form of hard roe and of their testes in the form of soft roe. In the breeding season, which

is autumn for English herrings, the fish come in-shore and swim in shoals in comparatively shallow water. This is the time when the big herring catches are made. At this time the females shed ova into the water and the males shed sperms over them, but, since there is no orderly arrangement of males and females in the shoal, the meeting of sperms and ova may be haphazard. Many ova and still more sperms are wasted. The ova which are fertilized develop at the expense of the small amount of yolk. The young herrings are an easy prey to larger fish, such as cod, and very few herrings attain maturity. Reproduction of fish is an excessively wasteful business.

QUESTIONS

1. *Describe the features of a bird's body which enable it to fly.*
2. *Why is a fish particularly adapted to life in water? In what respects does a tadpole resemble a fish?*
3. *Distinguish between growth and metamorphosis. Describe the metamorphosis of a tadpole into a frog.*
4. *Outline the method of reproduction in fish, frog and bird. State, with reasons, which method you consider to be the most efficient.*

CHAPTER XVII

INSECTS

There is no space in this book to make even a brief survey of all the invertebrate classes of animals, but we must pay some attention to the insect class. We are accustomed to think of man as the dominant animal of the world, and this is probably true, provided we hasten to add that the insects also occupy a very prominent position. There are at least a quarter of a million of different kinds of insects and many of them have been extraordinarily successful.

THE FEATURES OF AN INSECT AS ILLUSTRATED BY THE COCKROACH

The majority of insects are minute, and in their small size lies one of the secrets of their success, for they have been able to occupy nooks and crannies untenable by larger animals. One of the largest insects is the cockroach, and you will find it helpful to use this creature to gain some idea of the chief features of an insect (Fig. 98). Cockroaches can eat all kinds of food, and they are sometimes a pest in large kitchens and bakehouses where they exist on scraps of food and refuse.

The creature has a hard horny covering made of a substance called chitin, and the body is divided into three parts, the head, thorax and abdomen. Each of these parts is made up of segments. The head has a pair of long antennæ which possess sense organs of taste and smell. Round the mouth are the important structures shown in Fig. 98. The mandibles work across one another like a pair of scissors and enable the cockroach to bite its food, and the maxillæ and labium hold the food. The two pairs of wings on the thorax are outgrowths of the chitinous covering. The thorax has three pairs of jointed legs which enable the insect to scuttle rapidly across the floor when disturbed. The insect breathes by a system of air tubes which permeate every part of its body; these have paired

openings, the spiracles, on most. of the abdominal segments.

The insect lays eggs which have already been fertilized internally by the mating of male and female. In the cockroach the eggs hatch into minute replicas of the adult. Growth in the young insect is soon hampered by its resistant horny covering, and this splits, so that a soft-bodied creature emerges and proceeds to grow in size, while developing another chitinous

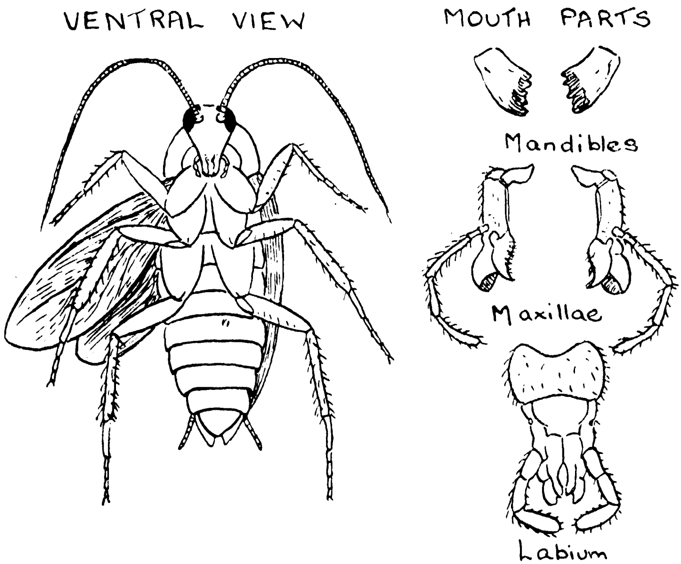


FIG. 98.—Cockroach.

covering. Shedding of the skin takes place several times before the insect is adult. In the soft-bodied condition immediately after each moult, the cockroach is an easy prey to its enemies. One of the drawbacks of the way of life of an insect is the necessity for casting the protective covering during the period of growth.

BUTTERFLIES AND MOTHS

Butterflies and moths lay eggs which hatch into a special kind of larva called a **caterpillar**. Thus there is metamorphosis in

the life cycle. Some caterpillars are very destructive pests, such as the caterpillar of the Cabbage white butterfly which devours cabbages, savoys, brussel sprouts and broccoli. The caterpillars of various kinds of clothes' moths eat woollen fabrics, furs, feathers and carpets. Other caterpillars are quite harmless so far as man is concerned, thus, the caterpillars of the Tortoiseshell butterfly and Red Admiral butterfly eat stinging nettles, while the caterpillar of the Cinnabar moth

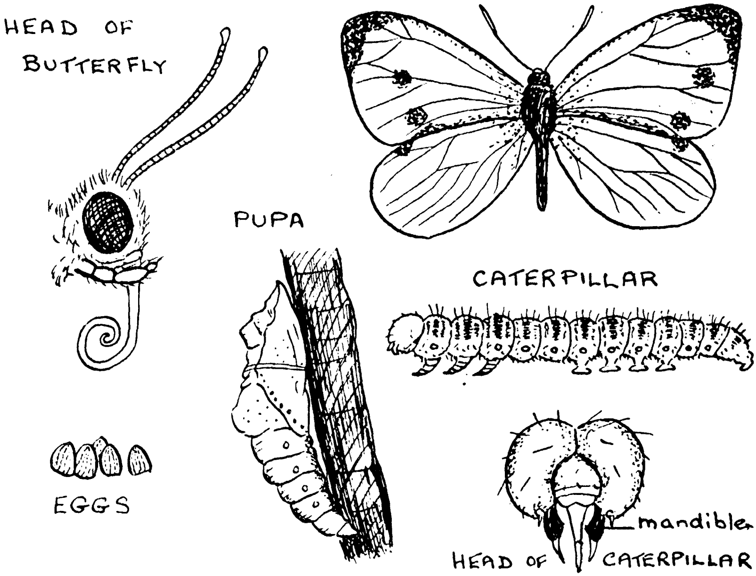


FIG. 99.—Cabbage white butterfly.

eats ragwort. The adult insect always lays its eggs on the plant or material which will form the food of the caterpillar.

The caterpillar of the Cabbage white butterfly (see Fig. 99) has a body divided into head, thorax and abdomen ; there are three pairs of short pointed legs on the thorax. These are used partly for movement and partly for holding the leaf while the scissor-like mandibles on each side of the mouth bite it. Caterpillars are voracious feeders, as you will know only too well if you have suffered their attacks on your cabbages. It is worth while removing the caterpillars by hand at an early

stage. Various dusting powders are on the market and these are only effective if they come into contact with the caterpillar.

On the abdomen are some pairs of sucker-like pads used for gripping on a surface, the suckers on the hindmost abdominal segment are sometimes distinguished as claspers. The caterpillar moves in a concertina-like fashion, gripping the surface with its posterior suckers, while it extends the anterior end of its body, then it draws up the hind end and continues.

When the Cabbage white caterpillar is first hatched in May it is only one-tenth of an inch long. During its six weeks of life it feeds and grows and casts its skin five times. In this period certain internal changes have been proceeding and at the last moult there is considerable external change. For this moult the caterpillar fixes itself in an upright position by three small pads of silk ; when the skin is cast the creature beneath has the appearance shown in Fig. 99. It is known as a **pupa,** and represents a resting stage which neither feeds nor grows. All the structures of the mature butterfly are there, neatly arranged in a small compass. After two weeks the pupal skin splits and the butterfly pulls itself out. Its wings are very crumpled and damp, and it remains motionless for a few hours, while these expand and dry.

Fig. 99 shows the mature butterfly. The surface of its wings is powdery because of the presence of numerous microscopic scales which overlap one another like the tiles on a roof. Coloured butterflies and moths also owe the colour and pattern of their wings to the nature and arrangement of scales.

The butterfly feeds on sugary liquids, chiefly on nectar from flowers. Its mouth appendages form a long coiled tube or proboscis which is used as a sucking apparatus. Normally, this is coiled up beneath the head, but it may be extended when the butterfly is feeding.

Butterflies mate on the wing and then the female Cabbage white butterfly lays its eggs on a suitable leaf in August. From these caterpillars hatch and they pupate about the end of September. The pupæ survive the winter and the butterflies emerge in April or early May. Thus, the Cabbage white butterfly has two broods a year.

The life history of other butterflies and moths is similar in fundamentals to that of the Cabbage white butterfly. Mention must be made of the Silk moth which is of great economic importance to man. The caterpillars are fed on mulberry leaves, and when they pupate, they spin a golden yellow case or cocoon inside which pupation takes place. These cocoons are unwound in the silk industry and the silk thread is woven into silk materials.

HOUSEFLIES

Houseflies are domestic pests, and they do more harm to

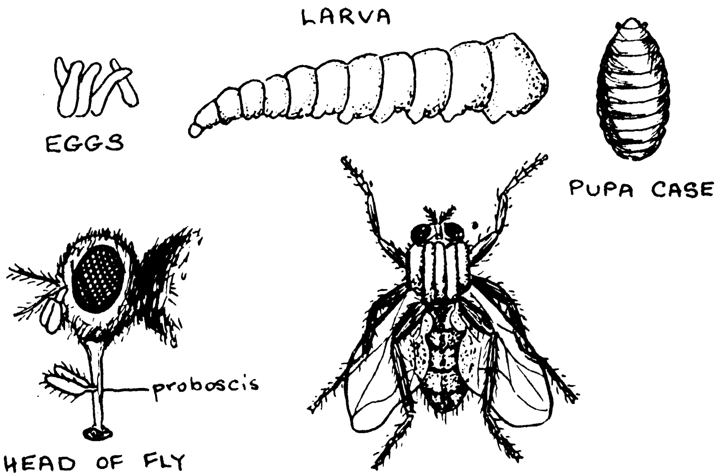


FIG. 100.—Housefly.

man than is generally realized. The fly sucks up liquid food by its proboscis (Fig. 100) ; it can liquefy certain solid foods, such as meat and sugar, by the secretion of enzymes from the end of its proboscis. Its food is very varied, ranging from garbage and manure to meat and jam. Now garbage and manure are the haunts of numerous bacteria ; many of these are concerned with putrefaction, and the vast majority do no harm to man. However, a few of the disease-causing bacteria can survive in putrefying material. As the fly walks in the manure and garbage its hairy body and legs become covered

with bacteria and the bacteria may also be swallowed with the fly's food. The next place where the fly alights may be meat or some other article of human food on which some of the bacteria are deposited. If the fly has been in contact with pathogenic bacteria, man may be infected when he eats the food. Flies can spread infant diarrhœa, typhoid fever and other diseases. In summer it is very desirable to keep food covered with gauze to prevent its becoming contaminated by flies.

Flies lay their eggs in manure heaps, or garbage, or in food. Bluebottle flies lay their eggs in meat. The eggs hatch after a day into legless maggots (Fig. 100), which feed by sucking from their surroundings. The pupa is formed after five days inside a hard orange-brown case (Fig. 100), and the adult fly emerges after four days. Thus, ten days after the laying of the eggs a new generation of flies is ready to lay more eggs.

GNATS AND MOSQUITOES

Gnats (Fig. 101) belong to the same group of insects as flies; in this group the insects have only one pair of wings. Adult female gnats feed by sucking blood of other animals through their probosces.

The eggs are laid in still water as a floating raft and the larvæ which emerge live in water in which they move by a wriggling motion. They breathe by means of air tubes, and therefore have to keep coming to the surface to gain fresh supplies of air at the main posterior spiracle. The pupa remains suspended from the water surface by its two main breathing tubes.

A mosquito leads a life similar to that of a gnat. One particular kind of mosquito is greatly feared in the tropics because of the part which it plays in the spread of malaria. Its relationship to the malaria germ is not a casual one like the relationship of the housefly to certain germs. The organism which causes malaria spends part of its life cycle in the blood of man and part in the body of the mosquito. The transference from man to mosquito can take place when a mosquito bites an infected man, and, after a period of development in

the mosquito, the disease spreads to more humans if they are bitten by the infected insect. The successful settlement of Europeans into Malaya and other tropical places has depended largely on successful war being waged against mosquitoes.

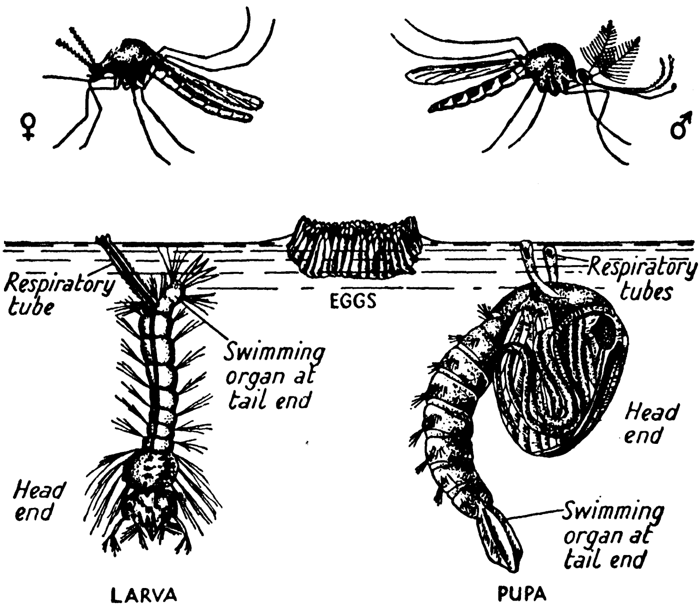


FIG. 101.—*Above*: Mature gnats, female (♀) and male (♂). *Below*: Stages in the life history of a gnat.

Adequate mosquito netting is only half the battle; by far the most effective treatment consists in the destruction of their breeding places by draining all the stagnant swamps within reach of dwellings.

GREENFLIES

Greenflies (Fig. 102) are very successful plant pests, they pierce holes in stems and leaves, and suck out cell sap. With an enormous number of such punctures through which sap is withdrawn the plants are seriously weakened. Greenflies will attack almost any kind of plant, but they are particularly abundant on roses, and the nearly related black aphis is a

serious pest on broad beans. The sap is sucked out at a greater rate than digestion and absorption can take place. Hence the excess food is discharged from the posterior end of the gut as a sticky liquid. Plants covered by greenflies are usually sticky.

Fortunately, greenflies have several enemies, including lady-

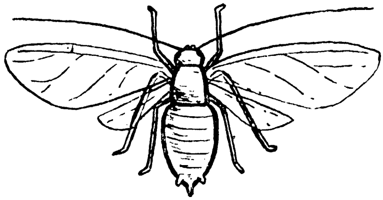


FIG. 102.—Greenfly.

birds, and they are very sensitive to unfavourable external conditions, such as rain and low temperature. They are most prolific in hot dry spells. Much of the efficacy of the various sprays used against them depends on the water alone.

Not only do greenflies inflict direct damage on plants, but they act as carriers of some virus diseases (see Chapter XIX, page 244).

BEES

Many of the insects we have mentioned so far are harmful to man or to his crops. On the other hand, bees are almost domesticated animals. The kinds of honey-bee kept by the bee-keeper are not native insects at all. The great interest of bees lies in the highly complex social life which they lead.

A beehive contains a series of vertically placed parallel frames of wax comb. The comb consists of hexagonal wax cells placed back to back, and its surface is covered by a jostling crowd of worker bees. A normal hive with 18 frames contains as many as 80,000 workers. Somewhere in the hive among the crowds of workers is the single queen bee. Much less numerous than the workers are the male bees or drones. If your school is lucky enough to possess an observation hive with glass sides you will find the watching of the many activities of absorbing interest.

Throughout the summer the queen is entirely occupied in laying eggs, and she is attended by a crowd of workers, which feed her and look after the eggs. The queen enters cell after cell, abdomen end first, and deposits a small white egg in each (Fig. 103) ; she may lay thousands of eggs a day. After three days the egg hatches into a white, legless, glistening, coiled larva (Fig. 103). This is fed by the workers, first on a semi-

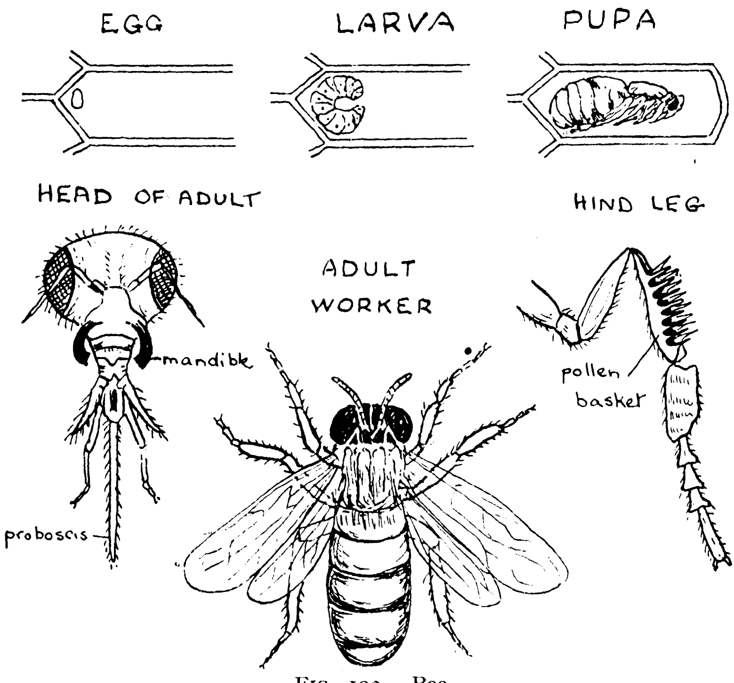


FIG. 103.—Bee.

liquid food very rich in protein made by the workers themselves, and then on a mixture of pollen and honey. After nine days, the workers put a wax cap on the cell and the larva sheds its skin and turns into a pupa (Fig. 103), which rests for about a week, and then the wings and legs extend, and the new worker bee emerges by biting off the cap of her cell.

Worker bees are females but they never lay eggs. In the summer they have a very short span of life of about four weeks,

but this short time is packed full of activities. Newly emerged worker bees look after the larvæ as described in the last paragraph. Workers of middle life are concerned with cleaning the hive and with the structure of the comb. They remove any refuse, including the dead bodies of their fellows, and they make new wax cells, using their biting mandibles to do so. Wax is made by bees from the food which they eat and it is secreted as small scales on the under side of the abdomen; these can be bitten off as required.

The older worker bees gather food by visiting flowers (Chapter XIII). Beekeepers are of great importance to the community, not so much because of the honey produced by the bees, but because of the part the bees play in the pollination of food crops, such as apples, beans, plums. Nectar from flowers is sucked up by the bee's proboscis and then it is conveyed to the honey sac or stomach where digestion of sucrose into glucose takes place. On arriving back at the hive the bee regurgitates the digested nectar in the form of honey into a wax cell. Honey is placed in a different part of the hive from the part where the eggs are laid, and, as each cell becomes full, it is covered by a wax cap. Pollen from flowers collects on the hairs of the bee's body, and at intervals the legs are used to brush off the pollen into a specially enlarged joint on the hind leg where it accumulates. Bees well laden with pollen have conspicuous yellow blobs on their hind legs, and in the hive the pollen is removed into cells. Bees seem to be very systematic in their food gathering, they visit flowers of one kind at a time, and they store the different kinds of pollen in separate cells.

The social life of bees is a system of orderly co-operation, and in some ways it compares very favourably with the turmoils of mankind. Their behaviour is instinctive and consists of a complex system of perfect reflexes (see Chapter XI). Bees do not have to learn their various activities, but on the other hand, they have little or no power of adapting their behaviour to new conditions.

Drone bees do not take part in the work of the hive, in fact, they are fed by the workers. Drones are of significance when mating occurs, for a queen bee cannot lay eggs until she has

mated with a drone. There is no space in this book to tell of the rearing of drones and new queens and of the process of mating and of swarming. You can read the fascinating story of these in Lulham's *Introduction to Zoology through Nature Study.*[1]

QUESTIONS

1. *Where do the following lay their eggs, and how do the larvæ feed : housefly, cabbage white butterfly, clothes moth, bee ?*
2. *Give an account of two insects which are harmful to man, with special reference to the damage they cause and to measures for preventing the damage.*
3. *Give some account of the community life of bees.*

---

[1] *Introduction to Zoology through Nature Study*, Lulham, published by Macmillan.

CHAPTER XVIII

SOME LOWLY PLANTS AND ANIMALS

Many different kinds of very tiny animals and plants live in water. Ponds often have green slimes of various kinds on the surface, and, if you mount a drop of water containing this slime and examine it under the microscope, you will probably see several other minute forms of life as well as the slime. Water containing organic matter abounds in minute animals. Put some manure into the bottom of a jam-jar and fill it up with water. Leave it for a week and then examine a drop of the mixture; you will find it teeming with minute animals darting hither and thither. Such simple forms of life must carry out the various essential life processes within the compass of their small bodies. Let us study a few of them a little more closely.

SPIROGYRA

The green pond slimes are, of course, lowly plants, and one of the most beautiful to examine under the microscope is Spirogyra. It is fairly common and you can recognize it partly because it is very slimy to the touch and partly because it is a much more intense green than the other pond slimes.

Under the microscope each thread appears as an unbranched filament of cylindrical cells (Fig. 104). Each cell has a thick sheath of mucilage outside its cell wall, but this mucilage has the same refractive index as water and it is difficult to see it unless it is stained. However, you can convince yourself of its existence by handling the Spirogyra before you mount it under the microscope. Inside the cell wall is the protoplasmic lining in which there is a spiral chloroplast which has wavy edges. Some kinds of Spirogyra have several chloroplasts in each cell. At intervals the chloroplast contains spherical structures round which starch is deposited. The centre of the cell is occupied by cell sap, and in this the nucleus is suspended

by delicate protoplasmic threads which attach it to the protoplasmic lining of the cell.

Now Spirogyra is a plant and, like the majority of plants, it carries on photosynthesis. Carbon dioxide is absorbed in solution by every cell and so also are the mineral salts necessary

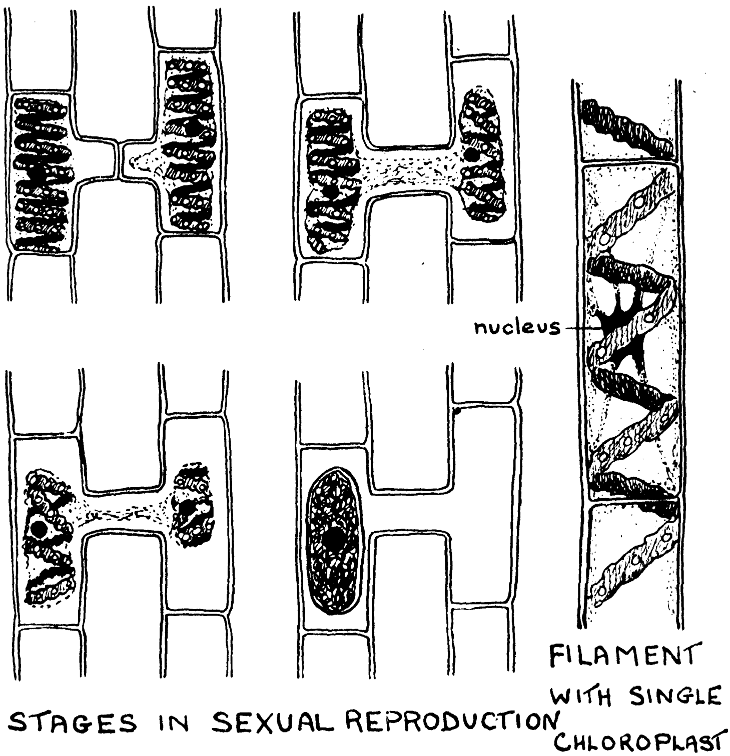


FIG. 104.—Spirogyra.

to build up proteins and to promote healthy growth. The oxygen given off in photosynthesis often appears as bubbles in the floating mass of Spirogyra.

Cell division occurs at intervals so that the filament continually increases in length. Fragmentation of long filaments may take place and then each of the small pieces forms a new filament. You will notice that although the cells are joined

together to form a filament there is no specialization of cells, each cell acts as a completely independent unit, carrying out its own absorption from the surrounding water, its own photosynthesis and its own growth.

Sometimes Spirogyra reproduces sexually by a method illustrated in Fig. 104. Two filaments become parallel and projections are put out by adjacent cells. These projections meet one another and fuse; at the place where they meet the cell wall is broken down, so that a clear passage from one filament to the other is formed. The contents of the cell in the one filament gradually flow across the passage and unite with those of the opposite cell. The resulting fused mass of protoplasm or zygote becomes oval and develops a thick cell wall. As a result of sexual reproduction between two filaments a row of thick-walled zygotes is formed in one filament while the other filament contains empty cells, because their contents have flowed to the opposite filament. The thick-walled zygotes are capable of resisting unfavourable external conditions. For instance, when the pond dries up only the zygotes survive. When the water supply is adequate again each zygote germinates into a new filament.

PLEUROCOCCUS

Pleurococcus is even simpler than Sprogyra, for it is a unicellular plant. It is found on damp wood surfaces, such as the south-west side of a tree trunk, exposed wooden fences and so on. Scrape off a little of the green powder into a drop of water and examine under the high power of the microscope.

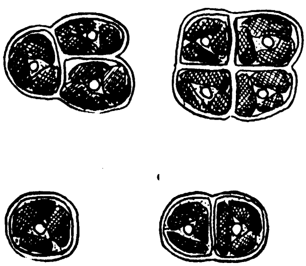


FIG. 105.—Pleurococcus.

The cell contains a complicated chloroplast in its lining of protoplasm (see Fig. 105). In ordinary times each cell is covered with a film of water from which dissolved carbon dioxide and mineral salts are obtained. Reproduction takes place by simple division, no sexual process is known. The new cells which are formed often

remain together in clumps of four or eight before they separate.

Pleurococcus seems to have the power of going into a resting condition during dry conditions and then it becomes active again when the water supply is adequate. Without this power of going into a resting condition it would not survive on trees and fences where the water supply is liable to fail during a dry period.

DIATOMS

Several kinds of unicellular plants live in ponds; in fact, you may have seen one or two of these when you examined the water containing Spirogyra. Some of the most interesting are the diatoms, which are unicellular brown plants (Fig. 106). They are abundant both in fresh water and in the sea. The cell walls are made of silica and are very hard. The cell contents contain a brown pigment in addition to chlorophyll, but photosynthesis proceeds normally. Actually the photosynthesis of the diatoms is a very important process, for diatoms are eaten in thousands by various small sea creatures which, in their turn, are food for fish. Similarly, in fresh water most of the animal life is directly or indirectly dependent on diatoms or various other unicellular plants.

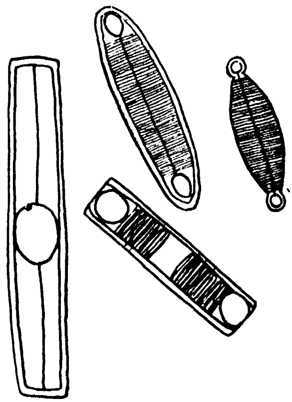


FIG. 106.—Various diatoms.

AMOEBA

Amoeba is one of the simplest animals known (Fig. 107). It lives on the mud at the bottom of a pond, but is not particularly abundant, and, if you want to be quite certain of seeing Amoeba, it is best to obtain it from a dealer. It is only just visible to the naked eye. Under the low power of the microscope it appears as a greyish mass of protoplasm containing many granules and a nucleus. It has an irregular

shape with several projections called pseudopodia. If you watch carefully you will find that the animal is changing its shape and that new pseudopodia are being formed while old ones are withdrawn. You will see a streaming of granules out into the new pseudopodia. When these have been formed, streaming takes place in another direction. You can make a record of the progress of the animal by making a series of outline drawings taken at half-minute intervals (Fig. 107).

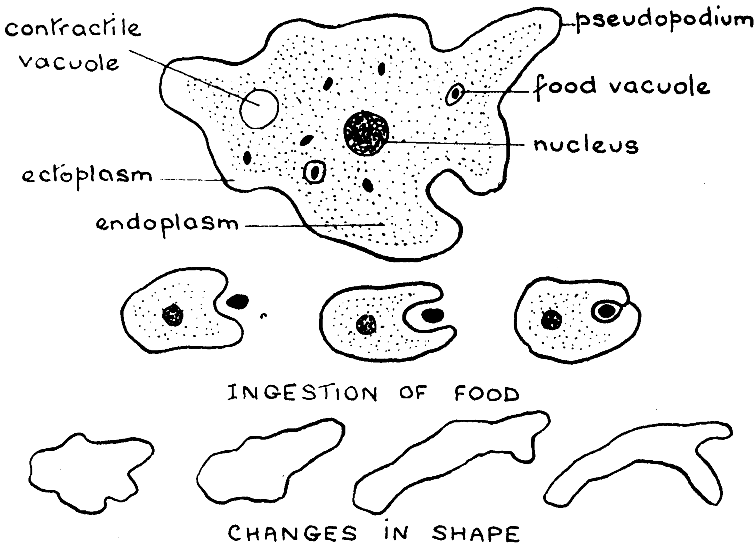


FIG. 107.—Amoeba.

The movement seems to take place by a squeezing action of the outer and somewhat stiff protoplasm (ectoplasm) on the more fluid inner protoplasm (endoplasm). By this method its rate of progression is comparatively slow. The animal feeds on diatoms. These are absorbed into the body during the streaming movements. If a pseudopodium comes into contact with a diatom it branches into two, one going each side of the diatom (Fig. 107). Subsequently the two branches meet one another again so that the diatom is now inside the body enclosed in a drop of water. This drop of water containing food is referred to as a food vacuole. Digestive enzymes are

secreted into the food vacuole so that the inner parts of the diatom are made soluble and are absorbed into the Amoeba's protoplasm. The outer wall of the diatom is very hard and cannot be digested; as the animal continues to move it is finally left behind.

During its progress through the water the Amoeba comes into contact with a good many foreign objects, not all of which have food value. All these objects are not absorbed indiscriminately. For instance, if a grain of sand is in the path of a pseudopodium the direction of streaming changes so that the grain is avoided. Ingestion in a vacuole seems only to take place if the particle concerned can be used as food.

Oxygen for respiration is absorbed in solution from the water all over the surface of the Amoeba; in a body of such limited dimensions special arrangements for oxygen supply are unnecessary.

As in all other animals various soluble waste products, including urea, accumulate in the course of metabolism. Water containing these waste products accumulates in a large vacuole which gradually increases in size. The vacuole appears as a large spherical space in the protoplasm. As you are watching it disappears suddenly and then starts to re-form as a minute vacuole gradually increasing in size to a maximum, when it disappears again. The disappearance of the vacuole is brought about by the squeezing action of the surrounding protoplasm so that its contents are squirted out into the water. The Amoeba gets rid of excess water and of soluble waste materials by the regular squirting out into the water. The vacuole concerned is called the contractile vacuole.

The Amoeba shows a considerable degree of sensitivity to external stimuli. We have seen that it responds differently to food particles and to grains of sand. Its movements are also determined by temperature and light; it will move away from extremes of either of these stimuli.

Reproduction of the Amoeba takes place by simple cleavage of the protoplasm into two halves; this is accompanied by the division of the nucleus, one of the new nuclei going into each half of the protoplasm. The two new cells separate away

completely and proceed to live quite independently, each grows to full size and then, if conditions are favourable, it divides again. You will notice that every part of the original parent is contained in one or other of the offspring ; in fact the original Amoeba goes on for ever in the bodies of its descendants. Indeed, Amoeba can truly be described as immortal ; it may suffer death by accident when it is eaten by a fish or when the pond dries up, but natural death is unknown to it.

PARAMECIUM

Among the very actively moving creatures in the manure and water mixture may be Paramecium, but, as with Amoeba,

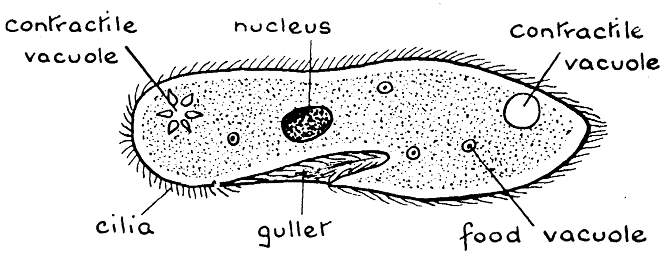


FIG. 108.—Paramecium.

if you want to be quite certain of seeing Paramecium, get it from a dealer (Fig. 108).

It is an oval flattened animal which moves extremely actively by the lashing movement of numerous fine protoplasmic threads or cilia which cover its body. It moves so much more quickly than Amoeba that it has gone right out of the field of view before you can see anything but its shape. To bring it to rest put some threads of cotton wool in the drop of water containing the animal. Then several Paramecia will be caught in the meshes of the cotton wool and you will be able to see them more closely.

On one side of the body (ventral as the animal swims) is a groove lined by actively moving cilia. This is the gullet. Food particles are wafted down the gullet by the action of the cilia and at the end the particles enclosed in drops of water are ingested into the protoplasm. These food vacuoles are

circulated in the protoplasm while digestive juices are secreted into them. Undigested solid residue is ejected to the outside.

Respiration takes place as in Amoeba and the excretory system is also fairly similar. Waste products accumulate in two series of radiating slit-like vacuoles. These enlarge and become pear-shaped at their proximal ends. As enlargement continues the ends coalesce completely and form a spherical vacuole which discharges itself just as in Amoeba. The two vacuoles at each end of the Paramecium cell work alternately; when one is ready to discharge itself the other is just starting to form its radiating canals.

Paramecium divides by cleaving into two. You will notice that it has two nuclei and each of these has to divide before the cleaving is complete. Like Amoeba the animal is potentially immortal. Paramecium can also reproduce sexually; two individuals unite and the product of union gives rise to eight offspring. The details of the sexual process are beyond the scope of this book.

HYDRA, A SIMPLE MULTICELLULAR ANIMAL

Amoeba and Paramecium each consist of a single unit of protoplasm, and in this small compass all the life processes are carried out. The bodies of the other animals we have considered consist of many thousands of cells and there is great specialization of different organs. You may be interested to examine one of the simplest multicellular animals to see the rudiments of specialization. Such an animal is Hydra, which lives suspended from water-weeds (see Fig. 109). There are several kinds of Hydra, some green and some brown, and, if you obtain Hydra from a dealer, it is best to ask for *Hydra fusca,* which is a large brown variety.

It has a hollow cylindrical body about $\frac{1}{4}$ inch long and is surmounted by a crown of tentacles which are constantly waving to and fro in the water. The tentacles surround the only opening into the body, the mouth. If you touch the Hydra with a needle, both body and tentacles shorten and thicken (Fig. 109). After an interval extension takes place again. There are various degrees of extension possible, and

the shape of the animal often alters in the course of its normal life in the water. It feeds on minute water creatures which are caught by special stinging cells on the tentacles, then conveyed by the tentacles through the mouth and so into the cavity of the body.

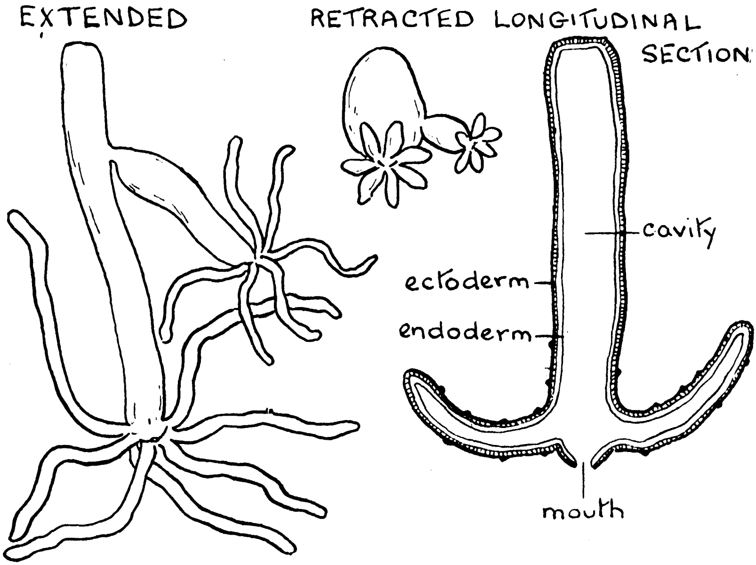


FIG. 109.—Hydra.

Fig. 109 shows a longitudinal section of Hydra, and you will notice that the body wall consists of two layers only, the ectoderm and endoderm, separated by a jelly-like layer. Both ectoderm cells and endoderm cells have muscular projections attached to them. The muscle projections of the ectoderm run longitudinally, those of the endoderm run in a circular direction. It is by the contraction of these muscles that the animal changes its shape. Some of the ectoderm cells become specialized as stinging cells, and others form a rudimentary series of nerve cells. In effect, Hydra is a hollow bag with tentacles. In the cavity of the organism digestion of food takes place, and digestive enzymes are secreted by the endoderm cells. Then the soluble products of digestion are absorbed. Un-

digested residue is passed out by the mouth. There is no circulatory system, and oxygen, food and waste products must pass from ectoderm to endoderm or vice versa by diffusion.

The animal can reproduce sexually, for testes and ovaries are produced from the ectoderm; one animal can produce both testes and ovaries, but they are seldom mature at the same time, so that the animal seldom fertilizes itself. Sperms are set free from the testes into the water and these swim to the ovary of another Hydra and fertilize the ovum. The zygote drops off the parent and develops after a period of rest.

In addition to the sexual method of reproduction Hydra multiplies by a method which is similar to vegetative reproduction in plants. Certain cells of the ectoderm start dividing actively and develop into a branch of the parent (Fig. 109). This is known as a 'bud', its cavity is continuous with the cavity of the parent, and it is fed by materials from the parent. When it grows to a larger size its own tentacles start to function independently and it feeds itself. Subsequently a constriction develops between the parent and the bud and at length the latter drops off and settles down elsewhere as an independent unit. Budding in Hydra is most active when food supply is plentiful and conditions in general are good.

THE GENERAL STRUCTURE OF THE EARTHWORM AS AN ADVANCE ON HYDRA

The segmented body of the earthworm consists of two cylindrical tubes separated by a cavity, the coelom, which is filled with liquid (see Fig. 110). The outer tube is the body wall and has well-developed muscles which enable the animal to extend and retract. Movement in the soil takes place by the stretching of the body followed by the pulling up of the posterior end. The movement is facilitated by the four pairs of movable bristles on each segment; when the anterior end is stretching out, the hind end is held firmly in the soil by the bristles.

The inner tube of the earthworm is the gut, and this has an opening at each end, viz., mouth and anus. It consists of a muscular wall and a glandular lining. The worm eats soil

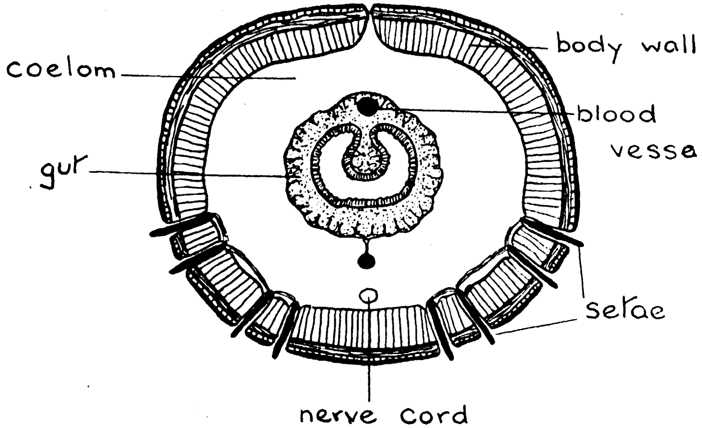


FIG. 110.—Transverse section of earthworm.

and digests the various kinds of organic matter found therein. The undigested residue passes out of the anus.

The plan of the earthworm's body is similar in fundamentals to that of all higher animals which consist of body wall and gut separated by coelom. There are obvious advantages in having a separate body wall and gut. In Hydra, movements concerned with digestion must concern the whole body. In the worm, bodily locomotion and digestive movements can proceed simultaneously and independently. As long as digestion concerns the entire animal little advance is possible, but once the gut is a separate entity all sorts of advance in structure and function are possible. The development of a separate gut cuts off the body wall from food supply and cuts off the gut from oxygen supply. Hence a circulatory system is essential.

THE TAPEWORM, A PARASITIC INVERTEBRATE

Several invertebrate animals live as successful parasites at the expense of other organisms. You will remember that dodder, a parasitic flowering plant, has a peculiar structure. Parasitic animals show many special features in accordance with their special mode of life.

The tapeworm (Fig. 111) lives in the intestine of man,

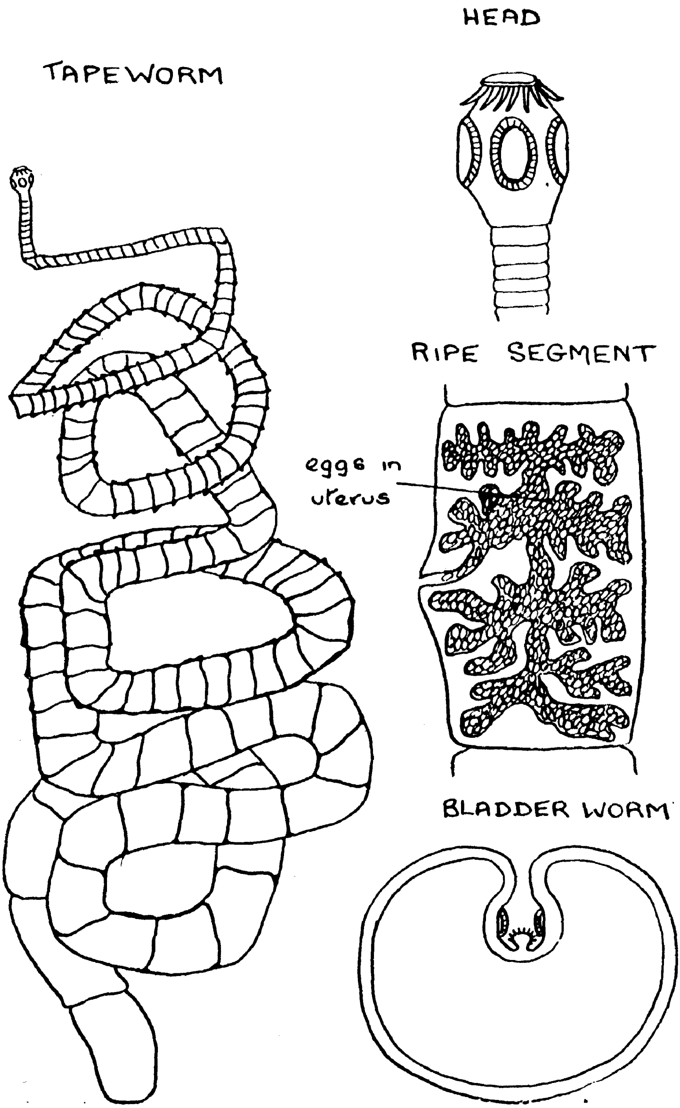


FIG. 111.

fastening itself to the wall of the intestine with the aid of suckers and hooks on its head. It has a very large number of segments which increase in size from the region behind the head downwards. The older segments drop off, but new ones are continually being made in the region behind the head. The tapeworm is surrounded by digested food and it absorbs this directly into its segments. There is no mouth, no alimentary canal and no circulatory system. It can perform sluggish writhing movements, but it lives a very sheltered existence without any enemies ; there are no sense organs and no nervous system. The most prominent structures in each segment are the ovaries and testes, each segment containing both, but the way in which fertilization takes place is not known. The fertilized ova become eggs which are encased in horny coverings.

The ripe segments, which drop off and are carried out with the fæces, contain a large number of eggs which have already developed into spherical masses of cells armed with hooks. Further development depends on successful penetration of another host. The tapeworm which attacks the intestine of man, lives in the pig as its alternate host. Pigs may often come into contact with human sewage and may swallow the young embryos of the tapeworm. In the intestine of the pig the shells are dissolved and the young embryos bore their way, via the blood stream, into the muscles of the pig, where they settle down and develop into the so-called bladder-worms (Fig. 111). The bladder-worm has the head of the tapeworm tucked into a large bladder. It absorbs food all over its surface from the lymph which is supplying the muscles.

Bladder-worms are moderately resistant to heat and may still be alive in under-cooked pork. If man eats under-cooked pork infested by bladder-worms the latter settle in the small intestine, the bladder part is digested, but the head is thrust out, fixes itself and starts to form segments.

You will notice that, in contrast to the simplicity of its other systems, the reproductive system of the tapeworm is very complex. Egg production is extremely prolific, for only a very small proportion of the eggs produced are likely to be picked up by a pig.

QUESTIONS

1. *Describe the structure of a cell of (a) Spirogyra, (b) Amoeba. On what grounds is Spirogyra classed as a plant while Amoeba is classed as an animal? (See also Chapter XX.)*

2. *Describe how the following move and feed: Amoeba, Paramecium, Hydra.*

3. *Describe the structure of the body of the Hydra. In what respects does the body of the earthworm show an advance on this?*

CHAPTER XIX

FUNGI, BACTERIA AND VIRUSES

It is customary to say that all living things are either animals or plants, but this is not necessarily true of three groups of organisms all of which are of considerable importance, namely, the fungi, the bacteria and the viruses. These are best regarded as three groups separate from the animals and plants.

THE FUNGI

Observations on the Growth and Life History of Moulds.—Some of the easiest fungi to study are the moulds which contaminate food. Bread and cake left about in a damp place usually develop a crop of moulds, one of which is a greenish blue one called *Penicillium*. Another kind of *Penicillium* is responsible for the rotting of oranges. Tomatoes often develop a white mould with black heads on it. This mould is called *Rhizopus*. A similar mould called *Mucor* sometimes appears on bread together with the *Penicillium*.

All moulds start life as spores; these are minute structures abundant in the air and on the surface of food. The greenish blue powder on the bread or the orange consists of many thousands of *Penicillium* spores. Similarly, the spherical heads on the *Rhizopus* and *Mucor* contain many spores. When food 'goes mouldy' it is because some of the mould spores, which are present everywhere, have found favourable conditions for growth.

Experiment 45.—Make an agar jelly containing water 100 gm., agar 2 gm., sugar 3 gm., sterilize it as directed in Experiment 4 (page 37) and then pour some of it into a watch-glass. Meanwhile, make a suspension of spores in water either of *Penicillium* or of *Rhizopus*. By leaving bread in a damp tin you can scarcely fail to get a good growth of *Penicillium*. To get *Rhizopus* prick some tomatoes several times and then keep them under a bell-jar lined with damp blotting paper. When the jelly has set in the watch-glass paint with a sterile brush the suspension of spores across the surface. Be careful not to use too

thick a suspension of spores. Examine the watch-glass under the microscope and see that the spores are sufficiently far apart. Now cover the watch-glass and leave the spores to grow. Examine under the microscope at least once a day. You will find that the spores swell considerably because they absorb a great deal of water. Then each spore puts out a delicate filament which soon elongates and branches (Fig. 112).

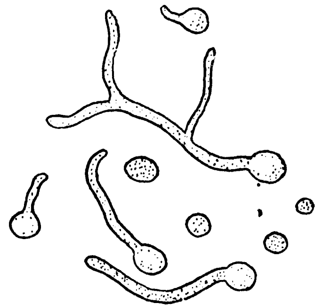


FIG. 112.—Germinating Rhizopus spores.

The filament is called a **hypha** ; it has a cell wall, not made of cellulose, and dense protoplasmic contents, without any chlorophyll. Soon there is a richly branched system of hyphae, spreading out just under the surface of the jelly in all directions. The hyphæ absorb food from the jelly, and you will realize that the enormous surface area of the hyphæ makes them very efficient as absorbing structures. Since there is a cell wall round the hyphæ everything must be absorbed in solution. In the jelly which you made, the nutritive materials are already dissolved, but on bread the insoluble starch and protein are dissolved by enzymes secreted by the hyphæ.

When an extensive system of hyphæ has been formed in the substratum, reproductive branches are formed. Spore-bearing branches will be formed on the fungus growing in the watch-glass and you can observe their development. They grow vertically, and then produce spores as shown in Fig. 113. You will notice that the *Rhizopus* spores are at first enclosed, while the *Penicillium* spores are exposed from the first. An enormous number of spores is produced. They are very well fitted to being dispersed by air currents, and a small percentage of them may land on material where they can grow. However, the vast majority of the spores are likely to be wasted, and this method of reproduction is necessarily extravagant. Some moulds, including *Rhizopus*, have a method of sexual reproduction, resulting in the formation of resting zygotes capable of withstanding adverse circumstances.

Moulds growing on bread and jelly are examples of sapro-

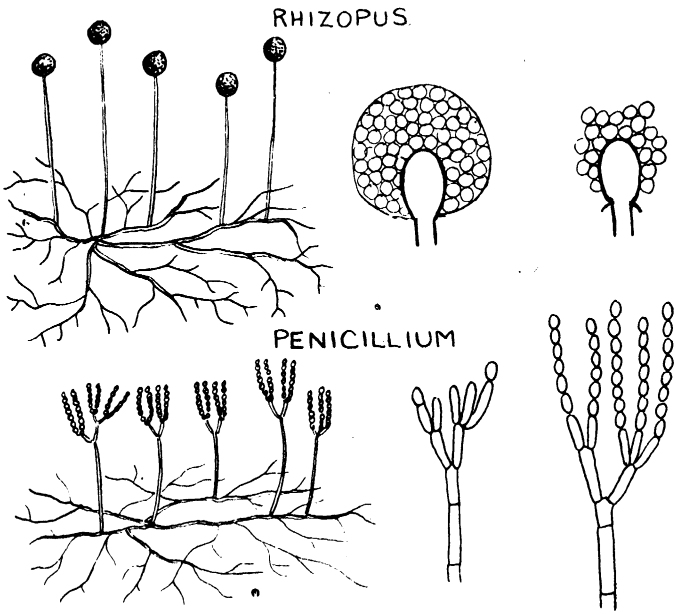


FIG. 113.

phytes. A **saprophyte** lives on dead organic matter (contrast with a parasite, Chapter VII, page 86). Moulds growing on fruits start as parasites and end as saprophytes.

Harmful fungi.—Moulds of various kinds cause considerable damage to stored food, particularly fruit. Spores are always liable to be present on the skins and, given favourable conditions, they will germinate and enter the flesh of the fruit ; as they break down the tissues, the fruit becomes soft and rotten. Subsequently an immense number of spores is formed on the fruit. The first fruit to be attacked by a mould is usually a damaged one, for the majority of moulds enter fruits far more easily through a wound than through the undamaged skins. Hence it pays to take great care in the picking and packing of fruit in order to prevent wounds. Cold storage too has beneficial effects in preventing rotting, because the spores cannot germinate at low temperatures.

Some fungi attack living plants and cause damage. Potato

blight is caused by a fungus, so also is rust of wheat, while other fungi can cause the rotting of the woody parts of trees. The fungi which attack living plants are all parasites. The potato blight fungus and the various rust fungi can attack their hosts via the stomata of the leaves, and thus prevention of the attack is difficult. Potatoes are often sprayed with Bordeaux mixture, which prevents the growth of the spores. Rust of cereals is best avoided by growing varieties which are not susceptible to attack.

Useful Fungi.—So far it would seem that fungi are harmful to man because they destroy his food. Actually, there are a great many fungi which do not impinge on man at all. Such are the vast majority of the toadstools, the hyphæ of which penetrate dead stumps, or grow on the leaf mould under the trees in a wood, or on manure in fields. A few of these toad stools, such as the mushroom, are edible.

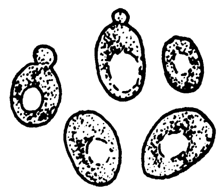


FIG. 114.—Yeast cells.

Some mould fungi are of use to man. Ripening of Gorgonzola and Stilton cheeses is due to the metabolism of special kinds of *Penicillium*. Still another kind of *Penicillium* is used for the extraction of the valuable drug Penicillin.

Yeast is a peculiar fungus which does not form any hyphæ ; it has oval cells which are continually dividing by a process of budding (see Fig. 114). Like other living things it uses sugar for respiration and oxidizes it to carbon dioxide and water. It respires actively provided the food and air supply are adequate ; and it is the carbon dioxide of respiration which causes dough to rise when yeast has been added. If you have learned how to make bread, you will know that dough rises best if it is kept in a warm place, where there is the most suitable temperature for the respiratory activity of the yeast.

Experiment 46.—You can easily demonstrate that yeast produces carbon dioxide. Set up a conical flask containing 200 c.c. of 10 per cent. sugar and 5 gm. of yeast. Put a stopper in the flask with a right-angled bend attached to a tube which dips under lime water. If you keep the apparatus in a warm place, you will find that the lime water

turns cloudy during the first hour and then goes clear again, as excess carbon dioxide is produced.

Yeast is also capable of respiring in the absence of free oxygen. It uses some of the oxygen from the sugar molecule itself to form carbon dioxide ; this leaves the rest of the sugar in a reduced condition as alcohol.

$$C_6H_{12}O_6 = \underset{\text{alcohol}}{2C_2H_6O} + 2CO_2.$$

This type of respiration, which takes place without free oxygen, is called **anaerobic respiration,** in contrast to the normal process, **aerobic respiration,** in which free oxygen is used. Very few organisms are capable of anaerobic respiration, because alcohol usually has a toxic effect. Yeast is tolerant of alcohol. Anaerobic respiration does not release nearly so much energy as aerobic respiration, and yeast, which is respiring anaerobically, seldom divides. You can demonstrate that yeast causes alcohol to be produced from sugar. The yeast in Experiment 46 soon uses up the available oxygen in the flask and then anaerobic respiration has to go on. So, if you leave the flask for a day or two, some alcohol will be formed. It is possible to obtain this alcohol, using a distillation apparatus. The alcohol boils off at 72° C. and may be collected. For full details of the method of distillation see the *Chemistry* book.[1]

Anaerobic respiration of yeast is made use of in wine-making and brewing. The principle of wine-making is extremely simple ; the grapes are crushed and then the yeast present on the skins starts to act on the grape juice. No wonder that wine has been known from very early times. Brewing is a little more complicated. Malt is made from germinating barley (see Chapter VII, page 85), and then yeast is added. The yeast acts on the malt sugar to produce a certain percentage of alcohol. Hops are added to beer to give the bitter flavour. The percentage of alcohol both in wine and beer is very low. Spirits, such as brandy and gin, are made by distilling mixtures of low alcohol content in order to obtain fairly pure alcohol.

[1] *Chemistry*, A. W. Wellings, uniform with this volume.

THE BACTERIA

Cultivation of Common Bacteria.—The structure of bacteria is simple, but their activities are very complex. They are extremely minute, and bacteria of one kind or another are present in the soil, in water, in the air and on the surfaces of all solid objects, including plants and animals.

Experiment 47.—Prepare four Petri dishes containing sterilized Bovril agar, using the instructions given in Experiment 4 (page 37). Open one dish and leave it exposed to the air for about an hour and then re-cover. Allow a fly to walk across the jelly in a second dish. Rub your finger along your back teeth, and then trace a cross on the surface of the jelly in the third dish. The fourth dish is to act as a control; if sterilizing has been perfect no living organisms should develop. The other three dishes will show living organisms of two kinds: there are radiating masses of fungal hyphae, each mass being due to the growth of a single spore, and there are compact slimy colonies of bacteria, each derived from a single bacterium which has divided repeatedly.

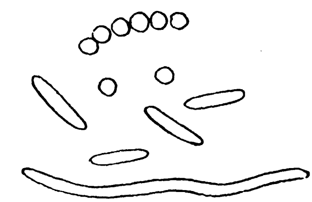


FIG. 115.—Bacteria.

By examining some of the bacteria in water under the high power of the microscope, you will find that the majority have the shape of short rods (Fig. 115). Some of them are so minute that they show a jerky motion as they are bombarded by the water molecules. A mixture of manure and water, similar to that used for demonstrating some lowly animals (see Chapter XVIII, page 220), is usually rich in bacteria. You will find that it contains many small rods, and, in addition, some much larger curved rods, which move actively by means of cilia.

Bacteria and Food.—Bacteria live on organic matter from which they obtain materials for respiration and for growth. Since there are cell walls round the bacterial cells, all substances must be absorbed in solution, and bacteria which live on insoluble organic matter produce enzymes which form soluble substances. Some of the chemical activities of bacteria are of great importance to man. We have already dealt with the activities of the soil bacteria (see Chapter III, page 37, and

Chapter VII, page 81). Bacterial action in food is often of great significance. Souring of milk is due to the activities of a bacterium ; scalding of the milk kills the majority of these bacteria so that souring is delayed until the few remaining bacteria have increased and multiplied. Spoiling of meat and fish is due to the action of various putrefactive bacteria similar to those which bring about the initial stages of decay in the soil. Some bacterial actions in food are desirable from man's point of view : thus, the formation of cheese from milk is due to bacteria, and so also is the production of vinegar from alcohol.

Certain bacteria have the power of converting sugar into alcohols of various kinds, in a similar way to the production of alcohol from sugar by yeast. Now, alcohols can be used as fuels as a substitute for petrol and the use of such fuels increases yearly.

Bacterial Diseases of Man.—Bacteria are not deliberately helpful or harmful to mankind. Like all other forms of life they must obtain food to use for growth and energy. The fact that the chemical activities of some bacteria affect man is purely incidental. This applies also to the parasitic bacteria ; there is no deliberate assault on the host, they are merely carrying out their usual life processes.

Parasitic bacteria can attack both plants and animals. Among the human diseases caused by bacteria are diphtheria, tuberculosis, typhoid, boils and lock-jaw. Many bacteria do not cause any ill effects until they enter the blood stream and some of them can only gain access to the blood through an actual wound ; such is the case of the lock-jaw bacterium, which persists in the soil in a resting condition, and then enters the blood through a cut. Bacteria causing septic poisoning of wounds have also entered through the open cut. Now you will understand the importance of applying an antiseptic of some kind to a cut.

Before the days of antiseptics, surgical operations of all kinds were usually fatal, not because the operation itself had been unsuccessful, but because bacteria causing septic poisoning entered through the open incision. In wars soldiers nearly

always died of their wounds, not because the wounds themselves were fatal, but because of gangrene poisoning caused by a bacterium. In these days the greatest care is taken to perform operations under sterile conditions; all instruments, dressings and swabs are sterilized, and both surgeons and nurses wear gauze masks to prevent contamination of exposed flesh by bacteria from their expired air.

The bacterium causing diphtheria invades the throat via the air which is breathed in. If the bacteria can be air-borne from one person to another the disease is very infectious. The tuberculosis bacterium, which attacks the lungs, can do so via the air which is breathed in. It can also gain access to other parts of the body by invading via the small intestine. In this latter case the chief source of infection is contaminated milk. The bacteria enter the milk from a cow which is suffering from tuberculosis. Milk can be an important source of infection of tuberculosis and it is very essential to ensure that milk is free of tuberculosis bacteria, especially if it is given to small children, who are very easily infected via contaminated milk. Tuberculin tested milk, which is the most suitable for infants, comes from cows which are guaranteed free of tuberculosis. Ordinary milk, which is supplied to school children, is subjected to a process of partial sterilization called pasteurizing. This consists in heating the milk to a temperature of 145° F. and maintaining it at this temperature for 30 minutes and then cooling it rapidly to 40° F. At the temperature of 145° F. the majority of bacteria, including those causing tuberculosis, are destroyed, unless they are in a resting condition. By cooling rapidly the resting bacteria are less likely to start germinating than if the temperature falls very gradually.

The symptoms of diseases due to bacteria are caused by chemical substances produced by the bacteria themselves. These are called **toxins**, and are transported all over the body by the blood stream. When there is a toxin present the blood tends to produce an **antitoxin** which neutralizes the toxin. The subsequent progress of the disease depends on the extent to which the toxins are neutralized by the antitoxins. If the toxins are all neutralized and the bacteria are killed complete

recovery takes place. When the toxins outweigh the antitoxins the patient gets worse.

Artificial Immunizing.—In the last century a great Frenchman named Pasteur noticed that animals which had suffered from an infectious disease and recovered, were less likely to develop this disease in future. He made definite experiments on the two diseases, chicken cholera and anthrax of sheep. He found that bacteria causing disease could sometimes be cultivated outside the animal, and the virulence of the bacteria depended on the age of the culture. A new culture was much more virulent than an old one. He inoculated sheep with an old culture of anthrax bacteria and they had the disease mildly and then recovered. After an interval, he inoculated these sheep and some others with a new and virulent culture of anthrax. The sheep, which had already had the disease, did not become ill, but the others succumbed to a fatal attack of anthrax. The sheep which had a mild attack of anthrax had produced the particular antitoxin needed; some of this must have remained in the blood stream, and, when the virulent culture of anthrax was introduced, the antitoxin was able to neutralize the toxin at once. The animals were said to be immune to the disease. This discovery of Pasteur's laid the foundation of the modern methods of preventing infectious disease by immunizing. Many of you will have been immunized against diphtheria.

We shall have a little more to say about immunizing when we are dealing with viruses. Meanwhile, remember that there is natural immunity as well as immunity artificially conferred. Bacteria in the blood stream are dealt with by two main methods: the white corpuscles ingest them (see Chapter V, page 55) and the appropriate antitoxin is made by the plasma.

THE VIRUSES

Virus Diseases of Man and other Animals.—In our list of infectious diseases caused by bacteria you may have been surprised at the omission of measles, mumps, chicken-pox and influenza. Now, there is no doubt that these diseases are infectious; they are all transmitted from one person to another

via droplets in the air; therefore, they are presumably due to the presence of living organisms. Yet, inside the diseased tissues, it is not possible to see any structures which may be designated as the agents concerned. Moreover, fluid from diseased tissues retains its infective powers after passing through the finest possible porcelain filters. These agents of disease, the viruses, are evidently ultra-microscopic, too small to be seen under the high power of the microscope. They are, perhaps, aggregates of complex protein molecules which have acquired the power of reproducing themselves. Some people have said that in the virus we have the most primitive kind of living organism. Others query this because they say that primitive life would hardly have attained so complex a way of living as the parasitic viruses. Perhaps, however, there exist many other non-parasitic viruses which are outside our ken at the moment, because we have no way of detecting them. We only know of the existence of the parasitic viruses by their effects.

Various other important diseases are due to the viruses. Foot and mouth disease of cattle is one of these. Yellow fever in humans is caused by a virus which seems to spend part of its life in a mosquito. The mosquito transmits the disease from one human to another. Small-pox is a virus disease, and this was the first disease to be prevented by artificial immunizing (vaccination), introduced by Dr. Jenner before the work of Pasteur. Vaccination consists in inoculating the allied disease, cow-pox, either into the arm or the leg. The baby suffers from an attack of cow-pox, which is seldom serious, and is successfully overcome by the generation of the necessary antitoxin. The antitoxin continues circulating in the blood stream for some years. It is capable of neutralizing the small-pox toxin as well as the cow-pox toxin, and therefore a vaccinated person is well armed against a possible epidemic of small-pox.

The common cold and influenza are other virus diseases, and work has been proceeding for some years on the possibility of immunizing against these tiresome and prevalent illnesses. The results attained are very variable; some people have

been successfully immunized, others are as susceptible as ever. Part of the difficulty is due to the fact that there is not just one kind of influenza or one kind of cold. Immunizing against a special type of cold will not make the person immune to another kind if he meets it and is susceptible to it.

Virus Diseases of Plants.—Plants suffer from virus diseases as well as animals. Potatoes, tomatoes and tobacco plants all have virus diseases. The most common virus disease of potatoes is known as leaf roll ; it causes considerable weakening of the plant with consequent reduction of the crop. It is transmitted from one plant to another by greenflies (see Chapter XVII, page 215) which suck up the virus when feeding on an infected plant. There seems to be evidence that the virus undergoes some change in the greenfly before it is transmitted to another plant. The virus in the potato plant spreads to the tubers, so that if the tubers are used for growing new plants these also will suffer from leaf roll. So prevalent is leaf roll that potato growers are always very anxious to plant tubers which are guaranteed free of the disease. Tubers obtained from Scotland are much less likely to be infected with virus diseases than English tubers, because greenflies are much less prevalent in Scotland, and so the virus diseases do not spread ; hence the demand for Scotch tubers by potato growers.

In your life-time much more will be known about viruses than at present ; keep your eyes and your ears open for the new discoveries.

QUESTIONS

1. *Explain the scientific reasons underlying the following practices : cold storage of fruit and meat, Pasteurization of milk, vaccination, use of antiseptics.*

2. *Describe the two methods by which yeast respires. For each method describe one practical application.*

3. *Write an illustrated account of one named mould, and show how it is particularly well adapted to its mode of life in respect of (a) vegetative structure, (b) reproduction.*

4. *Write notes on EITHER soil bacteria OR virus diseases of man. (See also Chapters III and VII.)*

5. *Answer the following :*

(*a*) *What are the natural defences of the human body against disease ?*

(*b*) *Why is the inside of a compost heap warm ?*

(*c*) *Explain how houseflies may transmit diseases.* (*See also Chapter XVII.*)

(*d*) *Why do farmers and gardeners set great store by Scotch potato tubers ?*

CHAPTER XX

LIFE

At the beginning of this book we set out to answer the question 'In what does the process of living consist?' Now it is possible to draw a few general conclusions.

We have seen that the forms of life are very diverse both in size and form, ranging from viruses which are too small to be seen and Amoeba and Pleurococcus which are microscopic, to man, elephants and oak trees.

All living things contain protoplasm, with the aid of which they carry out certain fundamental living processes. One of these processes is **nutrition** by means of which substances from the environment are absorbed, and undergo chemical action within the body, before being used to make new structural materials or to be kept as storage materials. With the help of the food **growth** takes place. Some of the food is oxidized to liberate energy in the process of **respiration.** Waste materials are got rid of by **excretion.** All living things **respond to external stimuli.** Finally, all living things multiply by a process of **reproduction.**

A living organism is sometimes described as a very complex engine, but it is doubtful whether the words 'very complex' are sufficient to emphasize the very great differences between a living organism and an engine. Even the most complex engine cannot construct its own body, or stoke itself, or get rid of all its waste so that it never needs cleaning, or make radical changes in its activity according to external conditions. Still less can it produce other engines exactly like itself. Yet even a lowly organism can do all these things.

We have seen that the majority of living things may be classed as plants or animals. The differences between the more complex plants and animals are very obvious. Animals have compact bodies and move about in search of organic

food which is directly or indirectly obtained from plants. Plants have diffuse stationary bodies, and, with the aid of chlorophyll, are able to build up their bodies from inorganic materials of their surroundings.

None of these differences is absolute. Some plants lack chlorophyll and have to live parasitically, e.g., dodder. Some lowly unicellular plants move. The ultimate difference between plants and animals consists in the possession of cell walls by plant cells while animal cells are naked. This means that a plant can only absorb soluble materials, and this is the case also in parasitic plants which absorb organic material in solution. Animals, on the other hand, can ingest solid particles.

We have said that living organisms show very great diversity. Yet in some respects you will have been struck by points of similarity. All mammals show much similarity to one another both in structure and functioning. You must have been struck by many points of similarity between rabbit and man. It is believed that mammals have a common ancestry, and this idea of **evolution** is generally accepted. Flowering plants also are believed to have a common ancestry. Actually, the idea of evolution goes much farther than this, for it would trace all vertebrate animals to a common ancestor and all plants to a common ancestor. This contention is supported by certain evidence and may be regarded as an accepted fact.

It is not yet so certain that the earliest ancestors of plants and animals were themselves derived from one common ancestor. Nor can we be sure that bacteria, viruses and fungi originated from the same common ancestor as other living things. In other words, it has not yet become clear whether life originated once and for all on the earth from one single form or whether there were several separate origins from separate forms. Many scientists argue that the composition of protoplasm seems remarkably constant and that this points to one origin of all living organisms.

Evolution points to the development of all living organisms from one or more original specks of protoplasm. Do not think that by tracing life to these original specks of protoplasm we have explained life or that we have destroyed its wonder, for

the story of evolution through long ages is full of wonder. And even more wonderful is the origin of the first specks of protoplasm, so very different in so many respects from the surrounding inanimate matter.

INDEX

Abdomen, 25
Absorption by plants, of water, 42–4; of mineral salts, 80
Accommodation of eye, 126–7
Adrenal glands, 145
Adrenalin, 145
Air, expired, 115–16; in soil, 34, 35; inspired, 115–16; tidal 114
Alimentary canal, 26, 90
Alveoli, 110
Amino acids, 68, 100.
Amoeba, 223–6
Ammonium salts, 79, 83, 84
Amylase, 91, 95
Annual plants, 3
Annual ring, 17
Antennae, 209
Anther, 155
Antheridium, 173
Anthrax, 242
Antirrhinum flower, 161–2; fruit, 164
Antiseptic, 240
Antitoxin, 241
Anus, 26
Aorta, 61
Apple fruit, 167
Archegonium, 173
Arteries, 57–8
Auricle, 61
Avens fruit, 169
Axil, 1

Backbone, 23–4
Bacteria and disease, 240–2; and food, 239–40; in large intestine, 96–7; in soil, 37–8, 81
Barbs, 194
Barbules, 194
Bean, seed of, 161, 184, 187; germination of, 186–8.
Bees, 216–19
Beri-beri, 101
Berry, 165
Biceps, 22, 23
Biennial, 4
Bile, 91, 94–5; duct, 90
Birds, 194–8
Birth, 179, 181
Bismuth meal, 94
Blackberry, 165
Bladder, 27, 30, 120, 121
Blood, 53 ff
Bones of limbs, 21, 22, 23; of trunk, 21, 24, 25
Brain, 137–8
Breast-bone, 25
Breathing of fish, 206–7; of frog, 199; of insect, 209; of mammal, 110 ff
Brewing, 85, 238
Bronchi, 110
Bronchiole, 110
Bud, 1, 7, 8, 9, 10, 11, 12
Budding, 172; of Hydra, 228, 229
Bulb, 9, 10
Buttercup flower, 155 ff
Butterfly, 210–13

Caecum, 29, 90, 103
Calcium salts, 36, 78, 80, 99, 101, 102
Cambium, 17, 18
Capillaries, 56–7
Carbohydrates, 65 (*see also* Sugar, Starch, Cellulose, Glycogen)
Carbon assimilation, 71–6
Carbon dioxide and photosynthesis, 73–4; produced in respiration, 107–8; removal of, 116, 120
Carpel, 156
Carrot, 4
Cartilage, 20
Caterpillar, 210–12
Cell sap, 15

Cell wall, 15
Cells of animals, 19–20 ; of plants, 15
Cellulose, 15, 67, 97
Centrum, 24
Cerebellum, 137, 138, 140
Cerebral cortex, 137 ; hemispheres, 137, 138, 140, 141
Chitin, 209
Chlorophyll, 15, 72, 74
Chloroplast, 15, 75
Cilia, 110, 226
Ciliary muscles, 126, 127
Clavicle, 21
Clay, 32, 33, 34, 35
Cleavers fruit, 169
Clematis fruit, 166, 168
Clothes, 123
Coal, 105
Cockroach, 209–10
Coelom, 229, 230
Cold, 243
Coleoptile, 189, 190
Colon, 26
Connective tissue, 20
Contact, response of plants to, 154
Cork, 17, 18
Corm, 9, 10
Corpuscles of blood, 53–5
Cotyledon, 160, 184, 187, 188, 189
Cow-pox, 243
Crocus, 9, 10, 154
Crop of bird, 197
Cuticle, 16
Cuttings, 36, 51, 171

Daisy, 5
Dandelion fruit, 166, 168
Decay, 38, 80–81
Deciduous trees, 11
Dehiscent fruits, 164
Delphinium flower, 162
Dentine, 27, 31
Dermis, 121, 122
Diabetes, 98
Diaphragm, 25, 112
Diastase, 85
Diatoms, 223
Diet of man, 99–103
Digestion 89, 92 ff
Diphtheria, 240, 242
Disease, 240 ff
Dispersal of fruits and seeds, 166 ff
Dodder, 86
Drone, 216, 218
Drupe, 165

Ear, 127–9
Earthworm, 37, 229–30
Effectors, 125, 132–135
Egg of bird, 197–8 ; of frog, 202
Elm fruit, 165, 166
Embryo of mammal, 177–9, 181–2 ; of plant, 160
Enamel, 27, 31
Endosperm, 160, 184, 189
Energy liberated from food, 105 ; of living things, 105 ff ; requirements of man, 99–100
Enzymes, 84–6, 91–2
Epicotyl, 187, 188
Epidermis of plants, 16 ; of skin, 121, 122
Epithelium, 20
Erepsin, 91, 95
Etiolated plant, 147
Evergreen trees, 11
Evolution, 247
Excretion, 119 ff
Eye, 125–7

Faeces, 97
Fats, 67–8 ; digestion of, 94–5 ; storage of, 67, 99
Feathers, 194 ff
Femur, 21
Fern, 172–4
Fertilization in birds, 197 ; in fern, 173 ; in fish, 208 ; in frog, 202 ; in mammals, 176–7 ; in plants, 159–60
Fibrin, 55
Fibrinogen, 55
Fibula, 21
Filament, 155
Fins of fish, 205
Fish, 205–8
Flight, 194–7
Flowers, 155 ff.

Food of mammals, 89 ff.; of plants, 70 ff.; for respiration, 108–9
Fowl, 194–8
Frog, 198–205
Fruits, 160, 164 ff.
Fuel, food as, 105
Fungi, 234 ff.

Gall bladder, 90
Gametes of mammal, 175, 177; of plants, 159
Gastric juice, 91
Geotropism, 153
Germination, 184–90
Gills of fish, 206, 207; of tadpole, 203
Gizzard, 197
Glands, 134–5, 144–6
Glucose, 66 (*see also* Sugar)
Glycogen, 67, 98
Gnat, 214–15
Gooseberry, 165
Grafting, 171–2
Grasses, flowers, 163; habit of, 5–6
Gravity, 150–3
Greenfly, 215–16
Grey matter, 136, 137
Growing point, 3
Growth, 184 ff.
Gullet, 26, 90, 93

Habits of plants, 3 ff.
Habitual actions (habits), 141–3
Haemoglobin, 54
Hairs, 121, 122
Hazel flower, 163–4
Heart, 26, 28, 29, 59–62
Herb, 3 ff.
Herring, 205–8
Hexose sugar, 66, 95
Hibernation, 200
Hive, 216 ff.
Hopkins, 101
Hormones of mammals, 144–6; of plants, 190
House fly, 213–14
Humerus, 21
Humus, 33, 39, 81
Hydra, 227–9
Hydrochloric acid, 91, 92, 93
Hydrotropism, 153
Hyphae of fungi, 235
Hypocotyl, 188, 189

Immunizing, 242, 243
Impulses, 135; afferent, 135; efferent, 135
Indehiscent fruits, 164, 165
Influenza, 243
Insects, 209 ff.
Instinctive actions, 140
Insulin, 98, 145
Intelligent actions, 143–4
Intestine, small, 26, 28, 29, 90 94–6; large, 26, 28, 29, 90, 96–
Invertebrate animals, 194, 209 ff 223 ff.
Iris of eye, 125, 126
Iron salts, 36, 78, 80, 99

Jenner, 243
Joint, 22; movement at, 22, 23, 133

Kidneys, 27, 30, 120–1
Klinostat, 152

Labium, 209, 210
Lacteal, 96
Lactic acid, 133, 134
Lactose, 66
Larva, 204, 211, 213, 215, 217
Leaf and photosynthesis, 74–5; roll, 244; structure of, 15, 16
Lens of eye, 125, 126, 127
Lenticel, 14, 17, 18
Lever, 133
Light and photosynthesis, 72, 74; as stimulus, 147–50
Lime fruit, 168, 169; twig, 11–14, 17, 18
Lipase, 91, 94
Liver, 26, 28, 29, 90, 91, 98–99
Loam, 34, 36, 37
Lungs, 26, 28, 29, 110 ff.
Lymph, 57

Magnesium salts, 36, 78, 80
Malt, 85–6, 238
Maltose, 66, 85
Mammal, 1, 194
Mammary gland, 179
Mandibles, 209, 210, 211
Manures, 81–4
Marigold plant, 1–3
Mating, 177, 181
Maxillae, 209, 210
Measles, 242
Medulla, 137, 138, 140
Menstrual flow, 181
Mesophyll, 16, 75
Metabolism, 65 (footnote)
Metamorphosis, 204 ; of bee (Fig.), 217 ; of butterfly (Fig.), 211 ; of fly (Fig.), 213 ; of frog (Fig.), 204 ; of gnat (Fig.), 215
Milk, 66, 67, 68, 91 ; bacteria in, 240, 241
Mineral salts in diet, 99, 100, 101 ; loss of, 119, 120, 122 ; needed by plants, 36–7, 77 ff.
Mint, 7
Mistletoe, 87
Mosquito, 214–15
Moulds, 234 ff.
Movement of bird, 194–7 ; of fish, 205–6 ; of flowers, 150, 154 ; of frog, 200 ; of leaves, 150 ; of mammal, 22, 23, 132–4
Mucor, 234
Muscles, 20, 22, 23 ; of alimentary canal, 90, 134 ; of body wall, 132–3 ; of heart, 61, 134 ; of internal organs, 134 ; of limbs, 22, 23, 132–3

Nectar, 155, 218
Nectary, 155
Nerves, 135 ff.
Neurone, 136
Nitrates, use by plants, 79
Nitrifying bacteria, 81
Nitrogen cycle, 81, 82
Nodules of Leguminous plants, 79
Nucleus, 15

Oesophagus, 26, 90, 93
Osmosis, 43
Osmotic pressure, 43
Ovary of mammal, 27, 30, 175 ; of plant, 156
Oviduct, 27, 30, 175
Ovule, 156
Ovum, 175, 177
Oxygen, absorbed, 116 ; carried by blood, 54, 116 ; needed in respiration, 105, 110 ff. ; produced in photosynthesis, 75–6 ; supply in plants, 117–18
Oxyhaemoglobin, 54, 116

Pain, 130
Pancreas, 26, 90, 98, 145
Pancreatic juice, 91
Paramecium, 226–7
Parasites, 86, 230, 237, 240 ff.
Pasteur, 242
Pasteurizing of milk, 241
Pectoral fin, 205, 206 ; girdle, 25
Pelvic fin, 205, 206 ; girdle, 25
Penicillium, 234–6
Penis, 120, 177
Pepsin, 91, 92, 93
Perennial, 5 ff.
Perianth leaves, 156, 157
Peristalsis, 93
Petals, 155, 156
Phloem, 17
Phosphorus compounds, 36, 78, 80, 83, 99
Photosynthesis, 71 ff.
Phototropism, 149
Pigeon, 194–8
Pituitary gland, 145
Placenta of mammal, 178
Plasma, 55–6
Pleura, 110
Pleurococcus, 222–3
Plum fruit, 165
Plumule, 160, 187, 188
Pollen, 155, 157 ff., 218
Pollination, 157–9, 161–4
Poppy fruit, 166, 168
Potassium salts, 36, 77, 78, 80
Potato, 7, 8, 9 , blight of, 237 ; virus diseases of, 244

Potometer, 49
Priestley, 76
Proboscis, 212, 213, 218
Proteins, 68–9; digestion of, 93, 95; in protoplasm, 100
Prothallus, 172, 173
Ptyalin, 91, 92, 93
Puberty, 179
Puddling, 51
Pulmonary artery, 61; vein, 61
Pulp cavity, 27, 31
Pulse, 58
Pupa, 211, 212, 213, 214, 215, 217
Pupil of eye, 126, 127

Radicle, 160, 187, 188
Radius, 21, 22
Receptacle, 155, 166, 167
Receptors, external, 125 ff.; internal, 131
Rectum, 26, 97
Reflex actions, 139–140, 141
Rennin, 91
Reproduction of bird, 197–8; of fish, 207–8; of frogs, 200–5; of fungi, 235, 236; of mammals, 175 ff.; of plants, 155 ff.
Respiration, 105 ff.; anaerobic, 238; of muscles, 133–4
Respiratory centre, 114
Retina, 125, 126, 127
Rhizome, 7, 8
Rhizopus, 234–6
Ribs, 21, 25
Rickets, 102
Root, 1, 2, 17, 18; hairs, 3, 34, 43; pressure, 51, 52
Roughage, 97
Rumen, 103
Runner, 8, 9

Sacrum, 25
Saliva, 91, 92, 93
Sand, 32, 33, 34, 35
Saprophyte, 236
Scapula, 21
Scurvy, 101, 102
Secretin, 144, 145
Seed, 160, 161, 187
Semi-permeable membrane, 43
Sense organs, 125 ff.
Sepals, 155, 156
Sexual reproduction in fern, 172–4; in mammals, 175 ff.; in flowering plants, 155 ff, 161; in Spirogyra, 221, 222
Shrubs, 11
Silk moth, 213
Skeleton, 21
Skin, 121 ff.; sense organs of, 130–1
Skull, 21, 27
Sleep movements, 150
Small-pox, 243
Smell, 129, 130
Soil, 32 ff.
Sperms of fern, 173; of mammal, 175, 177
Spinal cord, 24, 136, 137, 139
Spiracle, 210
Spirogyra, 220–2
Spleen, 58–9
Spores of fern, 172; of fungi, 234, 235
Stamens, 155
Starch, 67; digestion of, 91, 92, 93, 95; making of, in plants, 71, 76; storage of, 76, 77
Stem, 1, 16, 17; 18
Sternum, 21
Stomach, 26, 28, 29, 90, 93, 94
Stomata, 16, 46, 75
Storage materials, 65
Strawberry fruit, 166, 167; habit of, 8, 9
Structural materials, 65
Sucrose, 66, 67
Sugar, 65, 66; manufacture of, 71–5; respiration of, 105, 108, 109; using of, by plants, 76, 77
Sulphur compounds, 36, 77, 78, 80
Sundew, 87
Sunflower, germination of, 188, 189
Sweat glands, 121, 122
Sycamore fruit, 166, 168

Tadpole, 200–5
Tapeworm, 230–2

Taste, 129–30
Teeth, 27, 31
Temperature regulation, 122, 123
Tendon, 22
Testis, 175, 176
Thorax of mammal, 25; of insect, 209
Thyroid gland, 28, 145
Thyroxin, 145
Tibia, 21
Tissues of plants, 15; of animals, 20
Tomato fruit, 165
Tongue, 133
Touch, 130–1
Toxin, 241
Trachea, 110
Training of muscles, 133–4
Transpiration, 44–8
Transport materials, 65
Trees, 9–15
Tropism, 149
Trunk, 19, 23–7
Trypsin, 91, 95
Tuber, 7, 8, 9
Tuberculosis, 240, 241
Tulip, bulb of, 9, 10; flower of, 155 ff.
Turgidity, 43, 50

Ulna, 21
Umbilical cord, 178
Urea, 99, 120
Ureter, 27, 30, 120
Urethra, 30, 120
Urine, 120, 121
Uterus, 30, 175, 178, 180, 181

Vaccination, 243
Vagina, 30, 175, 180
Vane of feather, 194, 195
Vascular bundle, 16, 17
Vas deferens, 175, 176
Vegetative reproduction, 7, 170–2
Vein (blood vessel), 59
Vena cava, 61
Ventilation, 123–4
Ventricle, 61
Vertebra, 24
Vertebrate animal (definition), 194
Villi, 96
Viruses, 242–4
Vitamins, 101–3
Voluntary actions, 140–4

Water, absorbing power, 43; absorption by plants, 42–4; conduction in plants, 48–50; cultures, 78; evaporation in plants, 44–8; excretion of, 120, 121, 122, 123; in soil, 34, 35, 36; in tissues, 41; response of roots to, 153; supply in animals, 41, 43; use in photosynthesis, 73, 74
Weathering, 32, 33
Went, 190
Wheat, germination of, 189–90
White matter, 137
Willow herb fruit, 166, 168
Wilting, 50–51
Windpipe, 26, 28, 29, 110, 111
Wine, 238
Wings of bird, 194, 195, 196
Worker bee, 216, 217, 218

Xylem, 17

Yeast, 237–8

Zygote, 159, 177, 181